

Health and Environmental Impacts of Increased Generation of Coal Ash and FGD Sludges

Report to the Committee on Health and Ecological Effects of Increased Coal Utilization

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This paper focuses on the incremental impacts of coal ash and flue gas desulfurization (FGD) wastes associated with increased coal usage by utilities and industry under the National Energy Plan (NEP). In the paper, 1985 and 2000 are the assessment points using the baseline data taken from the Annual Environmental Analysis Report (AEAR, September 1977). In each EPA region, the potential mix of disposal options has been broadly estimated and impacts assessed therefrom. In addition, future use of advanced combustion techniques has been taken into account.

The quantities of coal ash and FGD wastes depend on ash and sulfur content of the coal, emission regulations, the types of ash collection and FGD systems, and operating conditions of the systems and boiler. The disposal of these wastes is (or will be) subject to Federal and State regulations. The one key legal framework concerning environmental impact on land is the Resource Conservation and Recovery Act (RCRA). RCRA and related Federal and State laws provide a sufficient statutory basis for preventing significant adverse health and environmental impacts from coal ash and FGD waste disposal. However, much of the development and implementation of specific regulations lie ahead.

FGD wastes and coal ash and FGD wastes are currently disposed of exclusively on land. The most common land disposal methods are impoundments (ponds) and landfills, although some mine disposal is also practiced. The potential environmental impacts of this disposal are dependent on the characteristics of the disposal site, characteristics of the coal ash and FGD wastes, control method and the degree of control employed. In general, the major potential impacts are ground and surface water contamination and the "degradation" of large quantities of land. However, assuming land is available for disposal of these wastes, control technology exists for environmentally sound disposal.

Because of existing increases in coal use, the possibility of significant environmental impacts, both regionally and nationally, exists regardless of whether the NEP scenario develops or not. Existing baseline data indicate that with sound control technology and successful development and implementation of existing regulatory framework, regional scale impacts are likely to be small; however, site-specific impacts could be significant and need to be evaluated on a case-by-case basis.

Both Federal and privately-funded programs are developing additional data and information on disposal of FGD sludges and coal ash. Continuation of these programs will provide additional vital information in the future. However, further information in several areas is desirable: further data on levels of radionuclides and trace metals in these wastes; studies on biological impacts of trace metals; and completion of current and planned studies on disposal problems associated with advanced combustion techniques like fluid bed combustion.

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Executive Summary

In meeting the requirements of the National Energy Plan (NEP), the Committee on Health and Ecological Effects of Increased Coal Utilization

commissioned 12 studies, including this paper. The paper focuses on the incremental impacts of coal ash and FGD wastes associated with increased coal usage by utilities and industry under NEP.

In this paper 1985 and 2000 are the assessment points using the baseline data taken from the Annual Environmental Analysis Report (AEAR, under ERDA Contract EE-01-77-0135, September 1977). In each Federal region, the potential mix of disposal options has been broadly estimated and impacts assessed therefrom. Potential impacts are dependent on the characteristics of the wastes and the disposal sites. Future use of advanced combustion techniques has been taken into account.

Technology and Production of Wastes

Coal-fired utilities and industrial boilers generate two types of coal ash: fly ash and bottom ash. Fly ash is collected by mechanical collectors — electrostatic precipitators, fabric filters, or wet scrubbers. Flue gas desulfurization (FGD) can be accomplished by nonregenerable or throwaway systems which result in FGD wastes and regenerable systems which produce a saleable product (sulfur or sulfuric acid). At present, 50,000 MW of coal-fired utility boilers are committed to flue gas desulfurization; 90% of these use nonregenerable systems. Nonregenerable systems require wet scrubbing technology. The four principal types of systems are those based on direct limestone, direct lime, alkaline fly ash and dual alkali. Lime, limestone, and fly ash systems are commercially available while dual alkali systems represent second generation processes now reaching commercial demonstration.

The quantities of coal ash and FGD wastes depend

on ash and sulfur content of the coal, emission regulations, the types of ash collection and FGD systems, and operating conditions of the systems and boiler. To meet New Source Performance Standards (NSPS), a typical utility operating at 70% load produces 100-500 tons of dry, ash-free sludge annually per megawatt of capacity. Using baseline data in the AEAR, production of coal ash and FGD wastes was estimated. The increased generation of coal ash and FGD wastes in each Federal region is shown in Table 1.

Disposal Options and Regulatory Considerations

At present, control technology for environmentally sound disposal of coal ash and FGD waste exists. This paper assesses the impacts on that basis. The disposal of FGD waste and coal ash will be subject to Federal and State regulations. While several Federal laws address disposal, the one key legal framework concerning environmental impact on land is the Resource Conservation and Recovery Act (RCRA). RCRA and related Federal and State laws (e.g., Clean Air Act and Federal Water Pollution Act) provide sufficient statutory basis for preventing significant adverse health and environmental impacts from coal ash and FGD waste disposal. However, much of the development and implementation of specific regulations lie ahead, including those with respect to wastes considered in this paper. Therefore, throughout this paper it is assumed that adequate regulatory authority exists but that potential impact issues require discussion so that future regulatory planning can focus on prevention or minimization of adverse impacts appropriately.

Table 1. Increased generation of ash and FGD wastes — cumulative^a.

Federal region	Coal ash only		FGD sludges only		Coal ash and FGD sludges	
	1985	2000	1985	2000	1985	2000
1	18	16	24	5	20	12
2	15	21	26	6	19	15
3	8	17	45	88	14	28
4	2	2	19	28	6	9
5	2	4	12	22	4	8
6	58	22	77	60	63	15
7	2	4	21	33	7	13
8	18	37	67	150	20	43
9	56	28	911 ^b	> 1000 ^b	64	38
10	104 ^c	147 ^c	596 ^b	616 ^b	119 ^c	166 ^c
National average	9	12	26	36	12	19

^aAll baseline data from the Annual Environmental Analysis Report (AEAR). Percentage incremental increase under NEP (over pre-NEP) is shown. All FGD systems assumed to be nonregenerable. Boilers assumed to meet NSPS standards in 1985 and BACT in 2000.

^bTotal sludge production in Regions 9 and 10 is low (less than 1% of national).

^cTotal ash and sludge production in Region 10 is low (less than 2% of national).

At present FGD wastes and coal ash are disposed of exclusively on land. Ocean disposal may be a technically feasible alternative but current regulatory disincentives preclude ocean disposal of FGD wastes and coal ash. In the future, ocean disposal of treated and sulfate-rich sludges may be carried out to a limited extent in regions where there are no mines available and disposal sites for land impoundments are scarce. However, if regulations constrain ocean disposal, use of regenerable systems would be employed in such regions.

The most common land disposal methods are impoundments (ponds) and landfills, although some mine disposal is also practiced. Future disposal methods assumed in each region are shown in Table 2.

Table 2. Disposal Methods.

EPA Region	Method
1, 2	Impoundment, landfill, ocean
3, 4, 5, 6, 7	Impoundment, landfill, mine
8, 9, 10	Impoundment, mine

The following impact assessments are based upon this assumed mix of disposal options.

Environmental Impacts

Environmental impacts are dependent on the characteristics of the disposal site, characteristics of the coal ash and FGD wastes, control method and the degree of control employed. Impacts are site-specific and cannot be easily generalized over a region. Furthermore, the existing regulatory framework, if successfully implemented, should prevent or minimize significant adverse impacts. Against this background, some broad generalizations on the potential environmental issues can be made on a regional or national basis. Potential impacts are assessed on the combined generation of ash and FGD waste by utility and industry. Regional baseline data are not available at present for industry alone, but wastes from industry will grow rapidly, becoming a very significant part of the national waste generation by 2000.

Potentially important impacts in most regions will not come from the differences between NEP and pre-NEP scenarios but with reference to the 1975 baseline, whichever scenario develops. Existing baseline data indicate that with sound control technology and successful development and implementation of existing regulatory framework, regional scale impacts are likely to be small; site-specific impacts could be significant and need to be evaluated on a case by case basis.

Land-Related. Projected incremental land requirements under NEP (over pre-NEP) for disposal of coal ash and FGD wastes are about 11% by 1985 and 19% by 2000. Projected total acreage involved under NEP is less than 21,000 acres by 1985 and less than 75,000 acres by 2000.* The existing regulatory framework, if successfully implemented, will minimize impacts on geology and soils. The magnitude of the incremental land use from a public policy viewpoint is not significant on a regional or national basis. However, the land required in a given locality could require modifications of land use planning and practices on a site-specific basis.

Water-Related. On a regional basis, hydrologic impacts are expected to be quite small. An important potential impact is the contamination of groundwater by leachate from the sludge/ash disposal area. In light of the existing data on sludge properties and on the effectiveness of the various controls, there appear to be adequate means for controlling the quantity of sludge leachate and, to some extent, its quality. Thus, the impacts due to the incremental sludge or sludge plus ash caused by NEP will become a site-specific question as to whether a potential disposal operation is feasible and to what extent control measures are required. Since regulatory authority is available to prevent deterioration of groundwater to the extent that its existing end-use is altered, impact on groundwater quality should be minimal.

Air-Related. Sludge and ash disposal methods entail significant levels of moisture in the disposed materials. Generally the high moisture content of the material would mitigate fugitive dust generation for most operations, and impacts on air quality on a regional basis would be small.

Biotic Impacts. Regional impacts on vegetation and wildlife are primarily a function of the additional

*EPA policy involves use of metric units; however, this paper uses some nonmetric units for the reader's convenience. Metric conversion factors are provided in Table 3 for readers more accustomed to the metric system.

Table 3. Metric conversion factors.

Nonmetric	Multiplied by	Yields metric
Acres	4048	m ²
BTU	1054.8	joules
	0.252	kcal
ft	0.3048	meters
ft ³	0.02832	m ³
in	2.54	cm
lb	0.4536	kg
mph	1.609	km/hr
psi	703.1	kg/m ²
tons	907.2	kg

land area required for landfill and impoundment disposal. Potential adverse impacts are: vegetation loss at the disposal site and effects on adjacent vegetation and habitat. Potential positive impacts include reclamation of surface-mined lands. Potential impacts on terrestrial or aquatic biota due to trace contaminants in leachate reaching surface waters are not well understood and need to be evaluated on a case by case basis. The existing regulatory framework provides mechanisms for the prevention of significant adverse biotic impact.

Health Impacts. As in the environmental impacts discussed above, the available regulatory framework, if successfully developed and implemented, should prevent adverse health impacts. With that in mind, potential impact issues can be: occupational (i.e., effects on workers in the disposal area); local (i.e., effects on persons near the site due to fugitive dust and impacts on local ground and surface waters; or remote (e.g., effect of materials, mainly trace metals, carried as leachate and turning up in water supplies.

The potential impacts in most areas would not come from the differences between the NEP and pre-NEP scenarios but with reference to the 1975 baseline, whichever scenario develops. Existing baseline data is limited but suggests that, with sound control technology and successful implementation of the existing regulatory framework, regional impacts are likely to be small. However, additional data are needed in this area.

Data Gaps and Research Needs

The Environmental Protection Agency (EPA), the Department of Energy (DOE), the Electric Power Research Institute (EPRI), and others have ongoing programs to develop more baseline data and information on disposal of FGD sludges and coal ash. Continuation of these programs will provide additional vital information in the future. In addition, from the environmental and health viewpoints, further information in several areas is desirable: data on levels of polycyclic aromatics (if any), radionuclides, and trace metals in these wastes; studies on biological impacts of trace metals including their potential synergistic impacts; and completion of current and planned studies on disposal problems associated with advanced combustion techniques like fluid bed combustion.

Introduction

Overview

The National Energy Plan (NEP) calls for study of the health and environmental impacts of increased

coal utilization. The Committee on Health and Ecological Effects of Increased Coal Utilization was established to fulfill this requirement. The Committee commissioned the preparation of a number of working papers to review the current state of knowledge on key topics concerning increased use of coal. This paper addresses the health and environmental impacts associated with the increased generation of coal ash and flue gas desulfurization (FGD) sludges under the proposed National Energy Plan (NEP). The paper was prepared by using the available baseline data in the Annual Environmental Analysis Report (AEAR), a MITRE report to ERDA under Contract EE-01-77-0135, September 1977.

Approach

The proposed National Energy Plan (NEP) emphasizes among other things conservation and increased energy efficiency and a shift toward increased use of coal with adequate environmental safeguards. The increased use of coal will lead to an increased generation of coal ash, including fly ash and bottom ash and flue gas desulfurization (FGD) sludges.

This paper focuses on the impacts associated with the disposal of the above wastes. Utilization of the above wastes in any commercial manner which is technically and economically feasible in many cases and any consequent impacts are excluded from this study. The following aspects of increased coal use are, among others, outside the scope of this paper: wastes generated during mining of coal, including coal washing; sources associated with the transportation of coal; direct air pollution associated with power plant emissions; sludges from water pollution control activities; and wastes from coal processing (liquefaction, gasification, metallurgical coking, and other direct use of coal in processing).

In order to place this assessment in perspective, the following are noted.

The incremental impacts associated with increased coal ash and FGD sludge generation have been the focus of attention. The two basic scenarios determining the incremental impact are: that under the proposed National Energy Plan (NEP) and that under restrained (except for EPA regulations) conditions described as pre-NEP. The incremental impacts and, where appropriate, baseline impacts in 1985 and 2000 were chosen as assessment points, using the AEAR. Important impacts in most areas will not arise out of the differences between NEP and pre-NEP scenarios but with reference to the 1975 baseline, whichever scenario develops.

Impacts associated with coal ash alone are examined separately from those associated with FGD

sludges and coal ash together. FDG sludge is frequently disposed of in combination with coal ash. Hence, the impacts of this combined disposal the impact of coal ash disposal alone are dealt with separately.

Both regional and national impacts are examined. Local and regional impacts are more important than averaged national impacts. Due to lack of baseline data, impacts associated with industry alone in each region have not been considered. Assessment has been based on the combined impact of industries and utilities in each region.

In each Federal region, a potential mix of disposal options has been broadly estimated and impacts assessed on this basis.

Potential impacts are dependent on the characteristics of the wastes and the disposal site. Therefore, it is necessary to integrate the method of disposal, type of control technology and the degree of control in light of these site-specific and waste-specific characteristics.

The current regulatory framework established by air, water and solid waste legislation, if successfully developed and implemented, would minimize or prevent sludge and ash disposal practices with significant adverse impacts.

Baseline data on waste generation does include probable contribution of advanced combustion techniques (like fluid bed combustion) for coal.

Present Technology and Production of Coal Ash in FGD Sludges

Coal Ash. Coal-fired utility and industrial boilers generate two types of coal ash: fly ash and bottom ash. Both constitute the noncombustible (mineral) fraction of the coal and the unburned residuals. Fly ash, which accounts for the majority of the ash generated, is the fine ash fraction carried out of the boiler in the flue gas. Bottom ash represents that material which drops to the bottom of the boiler and is collected either as boiler slag or dry bottom ash, depending upon the type of boiler.

The total amount of coal ash produced is directly a function of the ash content of the coal fired. Thus, the total quantity of ash produced can range from a few percent of the weight of the coal fired to as much as 35%. The partitioning of ash between fly ash and bottom ash usually depends upon the type of boiler. Standard pulverized coal fired boilers typically produce 80-90% of the ash as fly ash. In cyclone-fired boilers the fly ash fraction is usually somewhat less, 65-80% of the total ash created.

Fly ash carried in the flue gas stream can be collected in a number of ways to meet current particulate emission control limitations. Typical methods

include mechanical collection, electrostatic precipitation, fabric filtration and wet scrubbing. Mechanical collectors generally are not capable of meeting present emissions control limitations and, when used, are generally followed by either an electrostatic precipitator or high efficiency wet scrubbing systems.

FGD Sludges. FGD systems can be generally categorized into two groups: nonregenerable, or throwaway, systems which produce a waste material for disposal; and regenerable, or recovery, systems which produce a saleable byproduct (sulfur or sulfuric acid). There are now over 50,000 MW of coal-fired electric utility boilers in the United States to which flue gas desulfurization systems are being applied (including systems in operation, under construction, or in procurement). About 90% of this capacity involves nonregenerable systems, most of which employ lime or limestone to produce a solid waste, calcium-sulfur salt for disposal. This technology can be expected to dominate in boiler applications of flue gas desulfurization systems for the foreseeable future.

All commercial nonregenerable processes today involve wet scrubbing where gases are contacted at some stage with aqueous slurries or solutions of absorbent. Although most nonregenerable systems can withstand relatively high levels of particulate and trace contaminants and many in the past have been designed for simultaneous SO₂ and particulate removal, most systems being installed today, particularly on utility-scale boilers, follow high efficiency electrostatic precipitators in order to ensure a more reliable service. The notable exceptions to this are systems which utilize the alkalinity in the fly ash for SO₂ control and therefore frequently remove fly ash and SO₂ simultaneously.

The principal types of nonregenerable systems producing solid wastes for disposal are: direct limestone scrubbing, direct lime scrubbing, alkaline fly ash scrubbing, and double (dual) alkali scrubbing.

Most nonregenerable systems in operation today are lime or limestone scrubbing systems. These utilize a slurry of lime or limestone for SO₂ removal and can produce a waste ranging from a slurry to a relatively dry filter cake. Lime, limestone and flyash scrubbing are now considered to be a commercially available technology. A number of these systems have demonstrated high availability and reliability on utility-scale boiler applications. Double (dual) alkali systems represent a second generation technology which is now reaching commercial demonstration. Double alkali systems utilize solutions for sodium salts for SO₂ removal which are then reacted with lime outside the scrubber system to produce a waste discharged as filter cake.

The quantity of ash-free waste solids produced from nonregenerable systems is dependent upon a number of factors including: the sulfur content of the coal; the SO₂ emissions regulations; the type of FGD system and its operating conditions; and the boiler operating conditions. In general, the quantity of dry, ash-free sludge produced varies from 2.2 to about 3.0 times the quantity of SO₂ removed from the flue gas. A typical utility operating at a 70% load factor and meeting current New Source Performance Standards (NSPS) for SO₂ would produce anywhere from 100-500 tons of dry, ash-free sludge annually per MW of capacity.

Characteristics of Coal Ash and FGD Sludges

Coal Ash Characteristics. The chemical composition of coal ash (bottom ash, fly ash, and slag) varies widely, in concentrations of both major and minor constituents. Table 4 shows a compilation of chemical composition of both fly ash and bottom ash from the firing of a wide range of different coals. The principal factor affecting the variation in the composition is the variability in the mineralogy of the coal. However, differences in composition can exist between fly ash and bottom ash (or boiler slag) generated from the same coal due to differences in the degree of pulverization of the coal prior to firing, the type of boiler in which the coal is fired, and the boiler operating parameters and combustion efficiency. Regardless of the type of ash (either fly ash or bottom ash), more than 80% of the total weight of the ash is usually made up of silica, alumina, iron oxide, and lime. It should be noted that the compositional breakdown shown in Table 4 reflects only the elemental breakdown of the constituents reported as their oxides and not necessarily the actual compounds present.

While the major constituents of bottom ash and fly ash are generally similar, there is usually an enrichment of trace elements in the fly ash as compared with the bottom ash based upon the total quantity of trace elements in the coal fired. A few of the elements originally present in the coal (notably sulfur, mercury, and chlorine) are almost completely volatilized and leave the boiler as gaseous species which are not collected downstream in dry ash collection equipment. However, these can be collected in wet scrubber systems, as discussed later.

Up to 10% of fly ash can be water-soluble, so the potential exists for release of contaminants through leaching. The principal soluble species are usually calcium, magnesium, potassium, sulfate, and chloride. Leachates resulting from ash are usually alkaline due to the presence of calcium oxide and other alkaline species, although some ashes have

Table 4. Range of coal ash compositions.^a

Major constituents (wt %)	
Silica (as SiO ₂)	25-60
Alumina (as Al ₂ O ₃)	10-30
Ferric oxide (as Fe ₂ O ₃)	5-40
Lime (as CaO)	3.5-25
Magnesia (as MgO)	0.2-8.0
Potassium oxide (as K ₂ O)	0.1-4.0
Sodium oxide (as Na ₂ O)	0.1-4.0
Titanium dioxide (as TiO ₂)	0.5-2.5
Sulfur trioxide (as SO ₃)	0.2-20
Carbon and volatiles	ND-2
Selected trace constituents (ppm)	
Antimony	ND-200
Arsenic	ND-1,000
Barium	50-10,000
Beryllium	ND-200
Boron	15-6,000
Cadmium	ND-0.5
Chloride	—
Chromium	5-500
Cobalt	5-400
Copper	20-3,000
Fluoride	—
Lead	10-1,500
Manganese	50-10,000
Mercury	0.01-100
Molybdenum	5-1,500
Nickel	15-70
Phosphorus	5-10,000
Selenium	1-50
Thorium	—
Uranium	—
Vanadium	10-1,000
Zinc	25-15,000

^aSource: (1, 2).

been found to be inherently neutral or even acidic.

The physical properties of fly ash vary with the type of coal fired, the boiler operating conditions, and the type of fly ash collector employed. A mechanical collector, which generally removes only the heaviest fly ash fraction, produces a relatively coarse material with the consistency of a fine sand. In contrast, the ash removed in an electrostatic precipitator is usually finer, with silt-like grading. The range of specific gravities of fly ash depends upon particle size distribution and fly ash composition; however, specific gravities typically range from approximately 1.9 to 2.7. A small portion of the fly ash (< 4%) consists of cenospheres (hollow spheres) which have an apparent density less than water. Bulk densities of fly ash, because of the variations in specific gravity and particle size distribution, vary greatly. Bulk densities of fly ash, therefore, vary greatly, although the typical range for fly ash compacted at optimum bulk density would be 110-135 lb/ft³.

An important property of coal fly ash is its poz-

zolan activity. Pozzolan activity in fly ash either by the lime in it or by the addition of lime causes the fly ash to aggregate and harden when moistened and compacted. Because of the presence of pozzolan activity in some fly ashes, the engineering properties of fly ash vary greatly. In general, untreated fly ash (that to which lime has not been intentionally added) exhibits engineering properties similar to soils of equivalent particle size distributions. Permeabilities of compacted fly ash samples generally range from 5×10^{-5} cm/sec to 5×10^{-6} cm/sec. Treatment of pozzolan fly ashes with lime can result in significant increases in compressive strength and increases in permeability (depending upon the amount of lime, the water content, curing time, and degree of compaction).

Bottom ash can be collected either dry or in a molten state, in which case it is generally referred to as bottom slag. Dry-collected bottom ash is heavier than fly ash, with a larger particle size distribution. Since it has a similar chemical composition to that of fly ash, it behaves similarly, although pozzolan activity is usually somewhat less in bottom ash.

Boiler slag is a black glassy substance composed chiefly of angular or rod-like particles, with a particle size distribution ranging from fine gravel to sand. Boiler slag is porous, although not of so great a porosity as dry bottom ash. It is generally less reactive in terms of its pozzolan properties than either dry bottom ash or fly ash.

Because of the similarities between bottom and fly ash, they have been grouped together for environmental impact assessments. Both bottom ash and fly ash are frequently disposed of in pond disposal areas. Typically, bottom ash and fly ash would be sluiced to a central disposal pond where the ash would be allowed to settle out and the overflow liquor discharged or returned for sluicing. Analyses of pond liquors indicate total dissolved solids levels on the order of hundreds of ppm, the major constituents being calcium, magnesium, sodium, sulfate, and chloride, with lesser amounts of silicates, iron, manganese, and potassium.

FGD Sludge Characteristics. Both the chemical composition and the physical and engineering properties of the sludge produced by any FGD system at any particular time will depend upon a variety of factors including: the composition of the coal burned; the type of boiler and its operating conditions; the method of particulate control employed; and the type of FGD system and the way in which it is operated. Sludge characteristics, therefore, and the chemical composition in particular can vary over extremely wide ranges.

The principal substances making up the solid phase of FGD sludges are calcium-sulfur salts (cal-

cium sulfite and/or calcium sulfate) along with varying amounts of calcium carbonate, unreacted lime, inerts and/or fly ash. The ratio of calcium sulfite to calcium sulfate (the latter present as $\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O}$ or as gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) will depend principally upon the extent to which oxidation occurs within the system. Oxidation is generally highest in systems installed on boilers burning low sulfur coal or in systems where oxidation is intentionally promoted. Fly ash will be a principal constituent of sludge only if the scrubber serves as a particulate control device in addition to SO_2 removal or if separately collected fly ash is admixed with sludge. The amount of inerts and unreacted raw materials (lime and/or limestone) in sludges will depend upon the quality and utilization of raw materials (system stoichiometry). Table 5 outlines typical composition data on both.

A variety of trace elements find their way into FGD sludges from a number of sources: from coal where they are present either as mineral impurities or as organometallic compounds; from lime, limestone, or other reagents used in SO_x removal; and also from the process water make-up used. The greatest source of trace elements, though, is from the coal fired, and the levels of trace elements depend primarily upon their level in the coal, the amount, if any, of ash that is collected or admixed with the sludge, and the efficiency of the scrubber system in capturing trace metal vapors and fine particulates. Most of the elements in coal are not highly volatile and will be retained in the ash matrix (either as fly ash or bottom ash). The concentrations in the sludge of those elements that are most highly volatile (notably arsenic, mercury, selenium, beryllium, chloride, and fluoride) will depend upon the extent to which they are present and released from the coal, and more importantly, the efficiency with which they are cap-

Table 5. Properties of untreated FGD sludges (typical)^a

Category	Major chemical constituents (dry basis), wt %	Solids, %
Sulfate-rich	80-95% $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$	75-90
	0-10% $\text{CaSO}_3 \cdot x \text{H}_2\text{O}$	(filtered)
	5-10% CaCO_3 , MgCO_3 , Inerts ^b	50-65
Sulfite-rich	0-10% Solubles— Na^+ , Mg^{2+} , Ca^{2+} , SO_4^{2-} , Cl^-	(settled)
	pH = 6.5 – 8	
	40-85% $\text{CaSO}_3 \cdot \frac{1}{2} \text{H}_2\text{O}$	55-75
	5-50% $\text{CaSO}_4 \cdot x \text{H}_2\text{O}$	(filtered)
	5-10% CaCO_3 , MgCO_3 , CaO , inerts ^b	35-60
	1-10% Solubles: Na^+ , Mg^{2+} , Ca^{2+} , SO_4^{2-} , Cl^- , CO_3^{2-}	(settled)
	pH = 6.5 – 9	

^aSource: (2).

^bSilica and other nonreactive materials entering with lime and/or limestone.

tured in the FGD scrubber. Mercury and selenium are likely to be present in the flue gas as elemental vapors that might not be scrubbed efficiently. On the other hand, chlorides and fluorides are almost completely released from the coal and are very efficiently scrubbed. Fluorides usually end up in the solid phase of the sludge (as CaF_2), and chlorides, in the liquor phase (CaCl_2 is very soluble).

Liquid phases of FGD sludges contain dissolved in them a variety of substances ranging from traces of a variety of metals to substantial amounts of commonly occurring ions such as sodium, calcium, magnesium, chloride, and sulfate. As was the case with composition of sludge solids, concentrations of soluble substances in sludge liquors can vary by two orders of magnitude or more. The total dissolved solids (TDS) level can vary from about 2500 mg/l. to as much as 100,000 mg/l., depending upon the chloride/sulfur ratio in the coal, type of system, and the extent to which solids are dewatered (and washed), if at all. However, because of the insolubility of many of the trace metal hydroxides, only a very small fraction of the total amount of almost every trace metal present in the sludge is found dissolved in the sludge liquor. Tables 6 and 7 give ranges of trace element concentrations in FGD sludges, liquors and elutriates measured in samples from operating systems.

For the most part, FGD sludges are fine grained, with particle size distributions falling in the range of 5-50 μm , a range corresponding to silty to fine sandy soil. However, particles both smaller ($< 1 \mu\text{m}$) and larger (at least 200 μm) have been observed. Viscosity of FGD sludges and the extent to which they can be dewatered depend upon the size and shape of the crystals and the quantity of fly ash present. The highest viscosities have been observed for agglomerated sulfite-rich crystals. These become difficult to pump at greater than 40% solids. They can be typi-

cally thickened to 20-40% solids and filtered to 45-75% solids. The lowest viscosities have been observed for sludges containing a high fraction of gypsum and/or fly ash. These sludges can be pumped as slurries in concentrations as high as 70% solids or more. Sulfate-rich sludges can usually be thickened to 30-60% solids and filtered to 60-90% solids. These improved dewatering characteristics (which lead to lower volume and better handling characteristics) of sulfate-rich sludges are the rationale behind intentional oxidation in the scrubber system.

If the solids content of FGD sludges is increased sufficiently by filtration, centrifugation, or other means as addition of fly ash, they are amenable to compaction into a material which can be quite firm and which, if confined, can support considerable weight. The unconfined compressive strengths of such materials frequently range from nil to 50 psi or more.

Treatment of FGD sludges by the addition of lime and fly ash (or a similar source of silicate) can produce a relatively hard material when compacted. Such materials generally exhibit unconfined compressive strengths in the range of 100-400 psi (or higher). Treatment also tends to reduce permeability. Reported values of permeability coefficients for treated materials range from 10^{-5} to 10^{-7} cm/sec, as compared with 10^{-4} to 10^{-5} cm/sec for untreated compacted materials.

Preliminary data on leachate potential obtained from accelerated laboratory leach tests and field testing in ponds indicate that treatment, in addition to increasing strength and reducing permeability, may reduce the concentration of dissolved solids and the predominant soluble ions which constitute TDS in leachates. In addition, the improved handling properties of treated sludges in many cases permit better control of sludge placement and therefore better control of environmental impacts through

Table 6. Concentrations of trace elements in FGD sludges (typical).^a

Element	Concentration ranges, ppm	Median concentration, ppm ^b	Number of observations	Range of trace elements measured in coal, ppm
Arsenic	3.4-63	33	9	3-60
Beryllium	0.62-11	3.2	8	0.08-20
Cadmium	0.7-350	4.0	9	—
Chromium	3.5-34	16	8	2.5-100
Copper	1.5-47	14	9	1-100
Lead	1.0-55	14	9	3-35
Manganese	11-120	63	5	—
Mercury	0.02-6.0	1	9	0.01-30
Nickel	6.7-27	17	5	—
Selenium	< 0.2 -19	7	9	0.5-30
Zinc	9.8-118	57	5	0.9-600

^aSource: (2).

^bValues as reported.

Table 7. Concentrations of chemical species in FGD sludge liquors and elutriates (typical).^a

Species	Eastern coals			Western coals		
	Range in liquor, ppm	Median, ppm	Number of observations	Range in liquor, ppm	Median, ppm	Number of observations
Antimony	0.46-1.6	1.2	4	0.09-0.22	0.16	2
Arsenic	<0.004-1.8	0.020	15	<0.004-0.2	0.009	7
Beryllium	<0.0005-0.05	0.014	16	0.0006-0.14	0.013	7
Boron	41	41	1	8.0	8.0	1
Cadmium	0.004-0.1	0.023	11	0.011-0.044	0.032	7
Calcium	470-2,600	700	15	240-(~45,000) ^b	720	6
Chromium	0.001-0.5	0.020	15	0.024-0.4	0.08	7
Cobalt	<0.002-0.1	0.35	3	0.1-0.17	0.14	2
Copper	0.002-0.4	0.015	15	0.002-0.6	0.20	7
Iron	0.02-0.1	0.026	5	0.42-8.1	4.3	2
Lead	0.002-0.55	0.12	15	0.0014-0.37	0.016	7
Manganese	<0.01-9.0	0.17	8	0.007-2.5	0.74	6
Mercury	0.0009-0.07	0.001	10	<0.01-0.07	<0.01	7
Molybdenum	5.3	5.3	1	0.91	0.91	1
Nickel	0.03-0.91	0.13	11	0.005-1.5	0.09	6
Selenium	<0.005-2.7	0.11	14	<0.001-2.2	0.14	7
Sodium	36-20,000 ^c	118	6	1,650-(~9,000) ^c	—	2
Zinc	0.01-27	0.046	15	0.028-0.88	0.18	7
Chloride	470-5,000	2300	9	1,700-43,000 ^b	—	2
Fluoride	1.4-70	3.2	9	0.7-3.0	1.5	3
Sulfate	720-30,000 ^c	2100	13	2,100-18,500 ^c	3,700	7
TDS	2,500-70,000 ^c	7000	—	5,000-95,000 ^b	12,000	3
pH	7.1-12.8	—	—	2.8-10.2	—	—

^aSource: (3).^bLevels of soluble chloride components in sludges are dependent upon the chloride-to-sulfur ratio in the coal. The highest levels shown are single measurements for a Western limestone scrubbing system operating in a closed-loop using cooling tower blowdown for process makeup water.^cLevels of soluble sodium salts in dual alkali sludge (filter cake) depend strongly on the degree of cake wash. The highest levels shown reflect single measurements on an unwashed dual alkali filter cake.

better disposal site management. Sludge treatment processes are now commercially offered. Several such sludge treatment and disposal facilities are in full-scale operation on utility FGD systems in the U.S.

Regional Coal and Waste Relationships

Four representative coals were selected as the basis for the estimation of sludge and ash production rates: Appalachian, interior, Texas lignite and mountain. Table 8 summarizes the characteristics of these coals, and Table 9 gives assumed regional distribution of coal consumption by coal type and the predominant types of sludges produced by coal type and region. The coal characteristics reflect assumptions regarding coal cleaning prior to combustion.

Sulfate-rich sludges are produced predominantly from low sulfur coal where scrubber oxidation rates are highest. Thus, sulfate-rich sludges are assumed to be the predominant type of sludge produced from mountain coals. Since essentially all of the coal burned in Regions 7, 8, 9 and 10 is mountain coal, these regions would generate sulfate-rich waste.

Sulfite-rich sludge is produced from high sulfur coals. Therefore, sulfite-rich sludges would be produced from interior coal and would be the predominant type of sludge generated in Region 4.

With intermediate sulfur coals, either sulfate- or sulfite-rich sludges can be produced depending upon the type of FGD system and the boiler operation. In Regions 1-3, 5, and 6, the mix of coals would be expected to result in a mix of sulfate- and sulfite-rich sludges.

Table 10 shows the quantities of sludge and ash calculated for each type of coal under NEP and pre-NEP regulatory calculated assumptions. Under pre-NEP, an emission standard for SO₂ of 1.2 lb/10⁶ BTU is assumed for Eastern states and 0.6 lb/10⁶ BTU is assumed for Western states. Under NEP, 90% SO₂ removal and 90% scrubber availability are assumed for all coals and boilers.

Regulatory Considerations

The disposal of FGD sludges and coal ash is subject to regulations at both Federal and State levels.

Table 8. Coal/ash/sludge relationships (typical)^a.

Coal type	Coal region	Coal characteristics					Sludge type
		HHV, BTU/lb	Sulfur		Ash		
			%	lb/10 ⁶ BTU	%	lb/10 ⁶ BTU	
I	Appalachian	11,850	2.5	2.1	8.7	7.4	Sulfate- or sulfite-rich
II	Interior	11,419	4.1	3.6	10.3	9.0	Sulfite-rich
III	Texas Lignite	7,500	1.8	2.4	11.0	14.7	Sulfate- or sulfite-rich
IV	Mountain	9,000	1.03	1.15	9.2	10.2	Sulfate-rich

^aSource: (3).

State regulations governing waste disposal on land can be more stringent than corresponding Federal regulations.

At present, FGD sludges and ash are disposed of exclusively on land. Ocean disposal may be a technically feasible alternative. In the future, ocean disposal may be carried out to a limited extent in regions where there are no mines available and where disposal sites for land impoundments are scarce.

Disposal on Land. There are four major impact issues concerning land disposal: waste stability/consolidation, groundwater contamination, surface water contamination, and fugitive emissions.

These are essentially regulated under the Federal legislative framework listed in Table 11 and are briefly discussed below.

The Resource Conservation and Recovery Act is the major federal environmental legislation regulating disposal in mines, landfills and impoundments. Section 4004(a) of the Act requires development of criteria to classify disposal areas as either open dumps or sanitary landfills. The criteria will address land disposal broadly — including impoundments, land spreading and surface mine disposal. Following the promulgation of criteria, state plans will be developed so that existing open dumps will be closed or upgraded and future land disposal will meet sanitary landfill criteria. The criteria are expected to prohibit any groundwater contamination which would require additional groundwater treatment for intended

uses. To achieve the criteria in an environment where accessible groundwater is useful for potable or irrigation supply, it is likely that either: (1) the disposal sites would be lined or have adequate impermeability and soil attenuative capacity to protect groundwater quality (unlined sites must also have a contingency plan to control contamination when/if it occurs); or (2) the waste would be admixed with a fixation agent (e.g., fly ash and lime).

Under the Safe Drinking Water Act, states are required to adopt programs prohibiting underground injection of wastes without a permit. Regulations for

Table 10. Sludge and ash production rates by coal type.^a

Coal type	Sludge type	Annual tons of dry sludge/MWe ^b		Annual tons of dry ash/MWe
		pre-NEP ^c	NEP ^d	
I	Sulfite	210	240	225
	Sulfate	260	300	
	Avg. region	235	270	
II	Sulfite	420	420	275
III	Sulfite	250	280	450
	Sulfate	310	340	
	Avg. region	280	310	
IV	Sulfate	145	160	310

^aSource: (4).^b70% load factor; 10×10^6 BTU/MWe/t.r.^cAssuming NSPS = 1.2 for I, II, III; NSPS = 0.6 for IV.^dAssuming 90% SO₂ removal (90% available).Table 9. Coal/sludge/consumption relationships.^a

EPA Region	Approximate coal consumption, %				Predominant sludge type	Acre-ft/1000 tons dry sludge ^a
	I	II	III	IV		
1, 2, 3	100	0	0	0	Sulfite or sulfate	0.8
4	50	50	0	0	Sulfite	0.9
5	25	50	0	25	Sulfite or sulfate	0.9
6	0	10	50	40	Sulfite or sulfate	0.8
7, 8, 9, 10	0	0	0	100	Sulfate	0.6

^aSource: (3).^bAssuming no ash and typical sludge properties (compacted or settled).

Table 11. Federal regulatory framework for coal ash and FGD sludge disposal.

Impact issue	Legislation	Administrator
Groundwater contamination	Resource Conservation and Recovery Act of 1976	Environmental Protection Agency
	Safe Drinking Water Act of 1974	Environmental Protection Agency
Surface water contamination	Federal Water Pollution Control Act Amendments of 1972	Environmental Protection Agency
Sludge stability/consolidation	Surface Mining Control and Reclamation Act of 1977	Office of Surface Mining Reclamation and Enforcement
	Dam Safety Act of 1972	Army Corps of Engineers
	Federal Coal Mine Health and Safety Act of 1969	Mining Enforcement Safety Administration
	Occupational Safety and Health Act of 1970	Occupational Safety and Health Administration
Fugitive air emissions	Clean Air Act of 1974	Environmental Protection Agency
	Federal Coal Mine Health and Safety Act of 1969	Environmental Protection Agency
	Occupational Safety and Health Act of 1970	Occupational Safety and Health Administration

Source: (5).

the state underground injection control programs were promulgated by the EPA and apply to all deliberate subsurface emplacement of wastes by wells. The principal regulatory objective is protection of groundwater from endangerment of viable drinking water sources. This may influence underground mine disposal of FGD wastes.

There would be some relevance of FGD waste disposal to regulation of effluent discharges under the Federal Water Pollution Control Act Amendments. For example, some current Effluent Limitation Guidelines are based on the principal chemical constituents typically found in drainage from certain industrial activities. Introduction of a waste material could alter the designation of significant constituents which should be limited, as well as the final effluent concentrations which are achievable by available technology, resulting in a need to modify the Effluent Limitation Guidelines for the Utility or Mining industry categories. Similarly, new guidelines may be needed for discharges from landfill and impoundment disposal operation.

The Clean Air Act would be the primary vehicle for regulating fugitive emissions which may result from the handling and storage of FGD waste. Regulation would be accomplished under provisions of the Act requiring that no emitting source interfere with the achievement and maintenance of National Ambient Air Quality Standards (e.g., standards for particulates). In some cases, fixation of waste or dust suppression methods may be required.

Federal mine disposal regulation for purposes of groundwater protection would probably occur under

the Resource Conservation and Recovery Act, and disposal would have to meet sanitary landfill criteria. However, the physical stability of FGD storage piles or mine disposal would be regulated under the Surface Mining Control and Reclamation Act. Under this Act, placement of any waste within a surface mine is prohibited if it would pose an environmental or health hazard or cause physical instability of the mine area.

The physical stability of impounded wastes may be regulated under the Dam Safety Act. Under this Act, an initial inspection and inventory of existing dams was accomplished along with recommendations of dam specifications and inspection procedures to be included in further laws and regulations. Eventually states will establish their own programs consistent with federally provided model legislation and guidelines.

Standards promulgated under the Federal Metal and Nonmetallic Mine Safety Act are designed to protect miners from accident and disease. The standards would apply to air contamination from fugitive air emission of particulates or sulfur dioxide, to noise, waste stability, and safeguards for mechanical and electrical equipment. Similarly, standards promulgated under the Occupational Safety and Health Act would focus on protecting workers in all aspects of FGD waste disposal outside of the mine fence line.

Disposal in the Ocean. Regulation of dispersed ocean dumping of treated and untreated FGD waste falls under the Marine Protection Research and Sanctuaries Act and is administered by the En-

Environmental Protection Agency. The dumping would be required to occur at EPA prescribed dumpsites under the following conditions: trace contaminant (e.g., Hg, Cd) content of the dumped materials would be no higher than 50% above that of background sediments at the dumpsite; concentrations of the dumped material in the water column 4 hr after release would not exceed 1% of the 96-hr LC₅₀ of the material to local sensitive species; and no feasible alternatives to ocean disposal are available.

If treated, bricklike FGD waste is used to create artificial fishing reefs with EPA concurrence, the activities would not be subject to ocean disposal criteria.

Disposal and Utilization Options

Disposal. There are now a number of methods being employed for the disposal of FGD sludges and power plant coal ash. The most common method of disposal today is impoundment (ponds), although some mine disposal is also being practiced. In the future, in addition to impoundments, landfills (i.e., sanitary landfill disposal in which layers of waste are covered with layers of soil) would become a major option. The types of impoundments include both lined and unlined wet ponds and dry pits. In wet impoundments, sluiced ash or FGD sludge (often combined with ash) slurry is piped to the pond area where the solids settle out. The supernatant is then collected via overflow weirs and either discharged or recycled to the scrubber or ash sluicing system. Wet impoundments are used almost exclusively for on-site disposal at the power plant. In addition to the disposal of untreated wastes, they are sometimes used for treated materials (admixed lime and fly ash; or admixed lime, fly ash and FGD sludge).

Dry impoundments and landfills are used for the disposal of dry ash or dewatered (or treated) sludges. They can be either offsite or onsite; however, they are usually located close to the waste source because of the high cost of transportation. In dry impoundments or landfills, the wastes are collected and trucked to the disposal area. In landfills, the ash or sludge would be mixed with and then spread over layers of soil. In some cases, fly ash alone is spread as a cover material. The operation of a dry impoundment would be much the same except that untreated sludge mixed with ash (or treated sludge) would be layered in 6-in. to 1-ft. lifts and compacted.

There are three options for surface mine disposal of dry wastes: (1) disposal on the working pit floor prior to return of overburden; (2) dumping in spoil banks prior to reclamation; and (3) mixed with overburden. Sludge or ash would be transported to the mine via rail or truck and then truck-dumped in the

disposal area. There is a limited amount of fly ash and/or FGD sludge disposal now being practiced using the first two disposal options. Disposal of FGD sludges in active mines leads to less fugitive SO_x emissions because active mines are less acidic than inactive or depleted mines; therefore the sulfur compounds in the wastes are less likely to be dissolved (releasing SO₂) in the less acidic environment.

In a few instances, fly ash has also been disposed of in underground mines. The fly ash is sluiced and pumped into mine voids through boreholes. Supernatant can be recovered via dams and sump pumps and returned to a disposal basin or recycled for use in ash sluicing. No commercial scale FGD sludge disposal in underground mines is now being practiced.

All of these options will undoubtedly continue to be used in the future. However, based upon the impending regulations prohibiting groundwater contamination, unlined impoundments are expected to decrease in usage. Mine disposal is expected to increase in use due to the convenience and the elimination of the large tracts of land required for impoundments.

Ocean disposal of treated and sulfate-rich sludges may also be carried out to a limited extent in regions where there are no mines available and disposal sites for land impoundments are scarce. Ocean disposal could take the form of reef construction on the continental shelf (shallow ocean disposal) using treated material or dumping of treated or sulfate-rich material off the shelf (deep ocean disposal). Ocean disposal would probably be more likely to be practiced in Regions 1 and 2. However, should regulations constrain any form of ocean disposal, it is likely that use of regenerable systems would be employed in areas where land disposal is impractical.

Table 12 lists the potential disposal options and sludge types appropriate to each disposal option envisioned for the foreseeable future. Table 13 lists the anticipated significance of each disposal option in each Federal region. This disposal scenario was compiled based on current trends in regulations, existing data on characteristics of various types of sludges, and expected impacts associated with such operations.

Utilization. There are numerous uses of coal ash that have been developed both in the United States and Europe. However, at present, only about 20% of the total ash produced in the United States is being marketed. Fly ash, bottom ash and boiler slag, all of which comprise coal ash, are used in somewhat different applications. Only fly ash appears to be useful in FGD sludge treatment.

Some of the more important markets for ash in the United States include: manufacture of cement and concrete, light aggregate for construction, filler (and

Table 12. Sludge options vs. disposal scenarios.

Disposal scenario	Requirements	Sludge options
Land Disposal Landfill	Immediate workability Mixed with soil	Sulfate-rich (Dry) sulfite-rich Sulfate-rich + ash Sulfite-rich + ash Treated soil or brick
Managed impoundment	Immediate workability	Sulfate-rich Sulfate-rich + ash Sulfite-rich + ash Treated soil
Unmanaged impoundment	Lined pond	Any
Surface mine	Dry, soil-like	Same as landfill
Ocean disposal Shallow Dispersed	No (or low) COD availability ^a No (or low) ash Soluble	Sulfate-rich
Shallow con- centrated	Stable Low COD availability ^a Non-dispersing	Treated, bricklike
Deep con- centrated	Low TOS availability	Sulfate-rich Treated soil or brick

^aChemical oxygen demand (COD) is directly related to sulfite concentrations.

Table 13. Disposal scenarios (1985-2000).

EPA Region	Disposal methods (significance) ^a	
	FGD sludge	Ash
1 and 2	Impoundment (H)	Impoundment (H)
	Landfill (H) ^b	Landfill (H) ^b
	Ocean (H) ^c	Ocean (L) ^c
	Mine (L)	Mine (L)
3 and 4	Impoundment (H)	Impoundment (H)
	Mine (H)	Mine (H)
	Landfill (M) ^b	Landfill (M) ^b
	Ocean (L) ^c	Ocean (L) ^c
5, 6 and 7	Impoundment (H)	Impoundment (H)
	Mine (H)	Mine (H)
	Landfill (M) ^b	Landfill (M) ^b
	Ocean (L) ^c	Ocean (L) ^c
8, 9 and 10	Impoundment (H)	Impoundment (H)
	Mine (H)	Mine (H)
	Landfill (L) ^b	Landfill (L) ^b
	Ocean (L) ^c	Ocean (L) ^c

^aImportance (significance) of each disposal option described in parentheses: (H) = High in importance in the region; (M) = Medium in importance in the region; and (L) = Low in importance in the region.

^bLandfill refers to sanitary landfill type of disposal wherein the layers of wastes are covered with layers of soil.

^cIf regulations preclude all forms of ocean disposal, then it is likely that ash utilization and the use of regenerable systems would take up the slack where land disposal is impractical.

antiskid additive) for asphalt, landfill cover, extraction of mineral values, blasting (abrasion) compound, and soil additive.

In addition, there are numerous research and development programs being pursued to enhance existing markets and open new markets.

In contrast to coal ash, there are essentially no markets developed for utilizing wastes from non-regenerable FGD systems in the United States. In Japan, gypsum is produced in FGD systems and is marketed for use in wallboard production and the manufacture of cement.

However, in the United States, there is little or no current market for gypsum as a byproduct material. Other possible uses of nonregenerable wastes that continue to be explored include use as a fertilizer base or additive, a concrete additive, a low grade construction base for construction of artificial reefs, for soil amendments, and for fume subsidence control.

As an alternative to nonregenerable systems, regenerable systems produce sulfur or sulfuric acid as byproducts. Markets for these products, though, are quite limited and the cost for producing the byproduct with flue gas desulfurization systems is high. However, there are two circumstances under which the regenerable processes can find successful appli-

Table 14. Regional ash distributions: cumulative quantities.^a

Federal Region	1975 10 ⁶ tons	1985				2000			
		Pre-NEP, 10 ⁶ tons ^a	NEP, 10 ⁶ tons ^a	Δ, 10 ⁶ tons ^a	Δ/Pre-NEP, %	Pre-NEP, 10 ⁶ tons ^a	NEP, 10 ⁶ tons ^a	Δ, 10 ⁶ tons ^a	Δ/Pre-NEP, %
1	0.3	8.19 (4.10)	9.64 (4.82)	1.45 (0.73)	18	28.29 (14.14)	32.86 (16.43)	4.58 (2.29)	16
2	1.6	27.31 (13.66)	31.51 (15.76)	4.20 (2.10)	15	98.28 (49.14)	118.71 (59.36)	20.43 (10.22)	21
3	8.4	108.34 (54.17)	117.38 (58.69)	9.04 (4.52)	8	317.45 (158.73)	371.74 (185.87)	54.29 (27.15)	17
4	13.6	156.10 (78.05)	159.55 (79.78)	3.45 (1.73)	2	467.57 (233.79)	479.24 (239.62)	11.67 (5.84)	2
5	19.4	232.54 (116.27)	237.93 (118.97)	5.39 (2.70)	2	660.29 (330.15)	686.49 (343.25)	26.20 (13.10)	4
6	0.6	36.32 (18.16)	57.34 (28.67)	21.02 (10.51)	58	253.79 (126.90)	322.55 (161.28)	68.76 (34.38)	27
7	2.0	36.93 (18.47)	37.57 (18.79)	0.64 (0.32)	2	128.84 (64.42)	133.89 (66.95)	5.05 (2.53)	4
8	1.7	24.48 (12.24)	28.82 (14.41)	4.34 (2.17)	18	68.60 (34.30)	94.17 (47.09)	25.57 (12.79)	37
9	0.3	10.71 (5.36)	16.69 (8.35)	5.98 (2.99)	56	84.23 (42.12)	107.67 (53.84)	23.44 (11.72)	28
10	0.3	0.81 (0.41)	1.65 (0.83)	0.84 (0.42)	104	3.62 (1.81)	8.94 (4.47)	5.32 (2.66)	147
Total	48.2	641.73 (320.89)	698.08 (349.07)	56.32 (28.19)	9	2,110.95 (1,056.50)	2,356.26 (1,178.16)	245.31 (122.68)	12

^aNumbers of 1000's of acre-ft are in parentheses. Numbers may not add up to the last digit due to roundoff.

cation and would be used: in specific locations where a market for the products exists; in areas where availability of disposal options for nonregenerable processes is so constrained that the cost of waste disposal is high.

It is important to note that most regenerable systems also produce wastes; e.g., blowdown from pre-scrubbers (which remove fine particulate matter and chlorides from the flue gas prior to its entering the sulfur dioxide absorber) and blowdown of contaminants from the regenerative portion of the process.

Coal Ash-Related Impacts Projected Production and Trends

In order to gain an insight into the impacts associated with coal ash alone, estimates of the generation of coal ash and FGD sludges have been projected separately in each Federal region. The estimates on the generation of coal ash developed in the Annual Environmental Analysis Report have been used as the basis for these impact projections.

Table 15. Generation of coal ash: industrial utility breakdown.^a

	1985			2000		
	Pre-NEP, 10 ³ tons (% of total)	NEP, 10 ³ tons (% of total)	Δ, 10 ³ tons (% of total)	Pre-NEP, 10 ³ tons (% of total)	NEP, 10 ³ tons (% of total)	Δ, 10 ³ tons (% of total)
Industrial	9466 (11.7)	18,987 (20.7)	9521 (83.1)	21,977 (19.0)	43,518 (33.6)	21,541 (154.6)
Utility	71,011 (88.3)	72,947 (79.3)	1936 (16.9)	93,446 (81.0)	85,842 (66.4)	- 7604 (- 54.6)
Total	80,477	91,934	11,457	115,423	129,360	13,937

^aSource: (5). Basis: National Annual Waste Rates (Only boilers over 25 MWe included in industrial total)

Table 16. Generation of FGD sludges: industrial utility breakdown.^a

	1985			2000		
	Pre-NEP, 10 ³ tons (% of total)	NEP, 10 ³ tons (% of total)	Δ, 10 ³ tons (% of total)	Pre-NEP, 10 ³ tons (% of total)	NEP, 10 ³ tons (% of total)	Δ, 10 ³ tons (% of total)
Industrial	1200 (5)	6500 (20)	4900 (60)	5800 (15)	23,100 (40)	18,000 (95)
Utility	23,200 (95)	26,100 (80)	3300 (40)	32,900 (85)	34,600 (60)	1000 (5)
Total	24,400	32,600	8200	38,700	57,700	19,000

^aSource: (5)

The estimates presented in Table 14 include electric utilities and largescale industrial boilers (> 25 MWe). The data presented are the cumulative generation of fly ash through 1985 and 2000 under NEP and under pre-NEP conditions. Tables 15 and 16 present the overall national breakdown between industries and utilities. It is clear that industrial wastes grow rapidly and become a significant part of the total wastes. However, data on regional breakdown of industrial waste generation are unavailable as of this writing. Hence, the specific impacts associated with industry alone are not considered separately in this

paper. The impacts discussed are broadly caused by wastes from utilities and industries. Tables 8-10 outline the characteristics of coal, the quantities of ash produced from various coals, and the estimated mix of coals used in each EPA region.

The cumulative percentage increase of coal ash generated in each EPA region under the NEP (compared to pre-NEP) is shown in Figure 1. The incremental percentages increase of coal ash under the NEP is relatively small.

It should be noted that coal ash can be utilized commercially. (Examples of commercial utilization

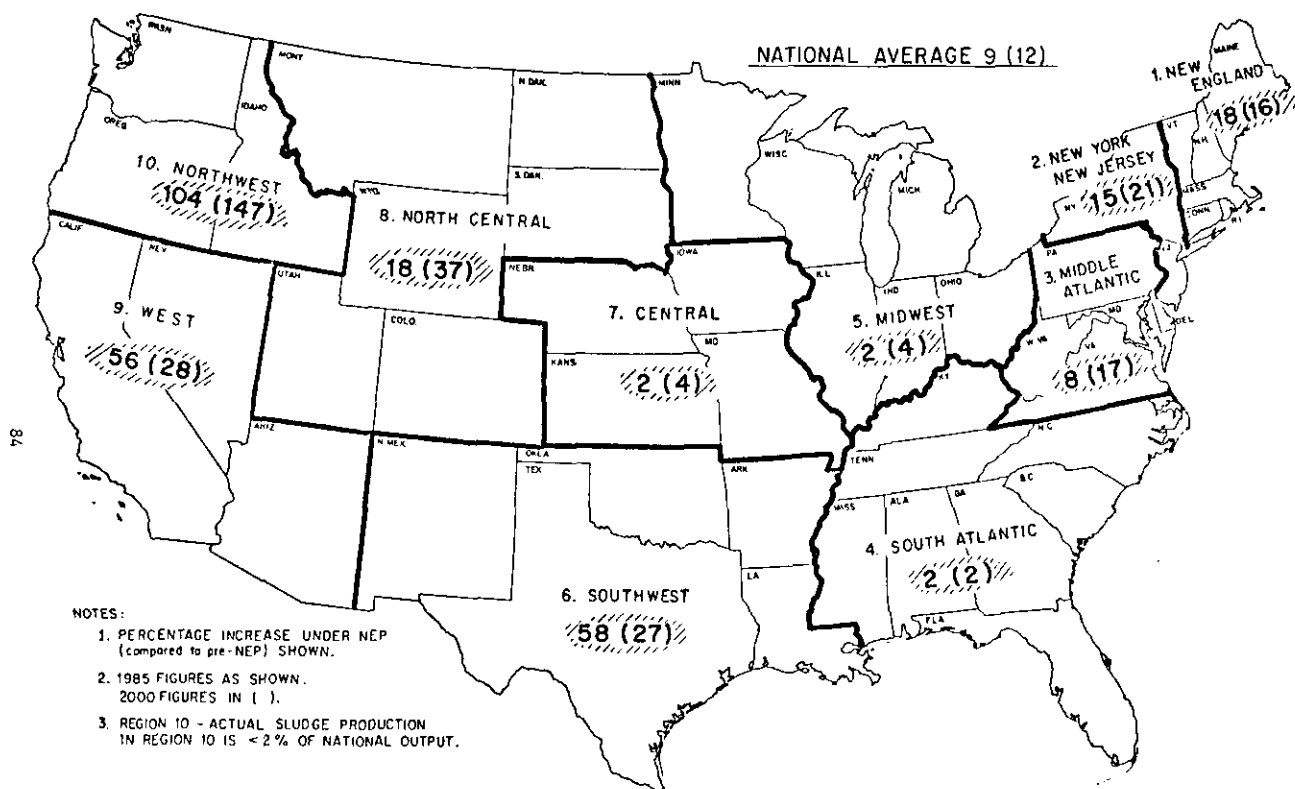


FIGURE 1. Regional coal ash generation cumulative percentages in 1985 and 2000.

include use in manufacture of cement, mixing with asphalt, and as light aggregate for concrete road beds); mixed with FGD sludge and subject to chemical treatment prior to disposal; or directly disposed of in landfills.

The net amount of coal ash, in particular fly ash, available for disposal independent of FGD sludge would be small for the following reasons. Assuming all FGD sludge were treated (or admixed) and that fly ash is required in the ratio of 50:50 to FGD sludge for treatment (in addition to lime), the net amount of fly ash left over for disposal/utilization is negligible except in Regions 6, 8, 9, and 10. Utilization of coal ash is likely to increase in future years.

The remainder of this section concerns impacts associated with direct disposal of coal ash alone.

In this paper, the combined impact of wastes generated by industries and utilities is addressed. Base-line data are not available as of this writing to consider the impact of wastes from industrial boilers alone. It should be noted, however, that preliminary estimates indicate that by 2000, the generation of such wastes by industry, which is presently negligible, will be a sizable percentage of the total generation of ash and FGD wastes.

Regional and National Environmental Impacts

The existing regulatory framework governing disposal of ash/sludge, if successfully implemented, should prevent or minimize significant adverse environmental impacts. Hence, discussion on environmental impact of ash or sludge disposal is basically an attempt to focus on potential environmental issues. The impact assessment in Sections 2.2, 2.3, 3.2, and 3.3 should be read against this background.

Land-Related Impacts. The additional land area required for cumulative disposal of coal ash if disposed of alone is not great. By 1985, the incremental land requirements under NEP (compared to that under pre-NEP) is about 9% on a national scale. By 2000, the incremental land requirements under NEP are only 12% which would amount to less than 5000 acres of direct disposal area.

Depending upon whether or not the particulate level from fugitive emissions is significant, disposal of fly ash could affect nearby land use patterns. Land-use regulations may restrict disposal to areas where residential, commercial or recreational activity is remote from the disposal area (i.e., buffer zones are required), thereby substantially increasing the land area temporarily affected by the disposal action. Adverse affects of coal ash disposal can be ameliorated by prudent engineering and design. Furthermore, commercial utilization of fly ash (as in cement

manufacture, as aggregate, etc.) reduces land use impact. On balance, land-related impact associated with coal ash disposal alone will be site specific. The overall incremental land requirements under NEP are such that the impacts on land use policy on a regional scale are not very significant in any region.

Water-Related Impacts (Coal Ash). The potential water related impacts are those of a hydrologic nature (This would be insignificant on a regional basis for coal ash disposal on an incremental basis under NEP) and those occurring as a result of leachate moving from the ash disposal area and impacting water quality.

As in all other impacts, site-specific implementation of available regulations and control technology to the appropriate degree is the overriding factor; if prudently applied and practiced, this could prevent adverse water related impacts.

A potentially important impact issue is that associated with the movement of leachate from ash disposal. The site-specific significance of contaminants in leachate depends on: whether the surrounding area groundwater is of very high quality or highly mineralized and attenuation, displacement, and dilution mechanisms which retard or prevent the movement of many chemical species in soil media.

Application of fly ash to soils could increase the availability of trace elements. The impact of leachate is also ash specific; chemical treatment and compaction reduce permeability.

It appears that movement of trace metals and principal chemical species (Ca, SO₄, Cl, etc. through soil into underground water) through leachates is one significant environmental impact issue. The regulatory objectives of RCRA, if successfully implemented, would prevent contamination of groundwaters to any level preventing continuation of existing use. This would impact siting considerations. The maximum incremental increase under NEP in coal ash production is likely in Regions 3, 5, 6, and 9. Region 10, while showing a large percentage increase, is not projected to be a major generation center.

Air Quality Impacts. A number of sources of atmospheric dust can be related to the disposal of coal ash. The dust generated from these sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream. Although no reliable emissions data exist for these sources, implications of potential impacts can be made based on the physical characteristics of the ash, the disposal methods and the climatological characteristics of the area. The dust generation process is comprised of two basic physical phenomena, which are particularly applicable to dry materials: pulverization and abrasion of surface material by the application of

mechanical force during the disposal operation (loading, transporting, dumping, etc.); and entrainment of dust particles by the action of turbulent air currents. Airborne dust may also be generated independently, by wind erosion of an exposed surface if the wind exceeds approximately 12 mph.

The air pollution impact of fugitive dust from coal ash disposal depends on the quantity and drift potential of dust particles emitted into the atmosphere. The emission rate depends on the properties of the coal ash and the activity level in the disposal process. The physical characteristics of typical ash pertaining to potential fugitive emissions are given in Table 17.

Coal ash disposal can involve wet or dry material. At present, wet methods are favored, but regulatory guidelines may encourage a trend toward dry handling. Even on dry systems, use of water and possibly dust mitigating agents is expected to be required during field operations to minimize fugitive dust.

It should be noted that the moisture content of coal ash is generally well above the level of 5% by weight, the amount required to totally mitigate emissions of fugitive dust. Therefore, it can be assumed that the emissions of fugitive dust, assuming sound disposal practice, would be quite small regardless of the disposal procedure as long as the moisture content remains large. However, airborne dust may be generated in disposal processes that allow the surface material to dry to levels below 4-5% moisture content.

Nearly 85% of the coal ash by weight (see Table 14) is less than 75 μ m in particle size. Thus, disposal procedures that allow for surface exposure for extended periods of time would allow for evaporation and drying of the exposed surface particles and could cause emissions of fugitive dust. Landfill and surface mine disposal procedures are the two options that could cause increased fugitive emissions unless reasonable mitigative measures were undertaken. The regions that utilize landfill and surface mine disposal options could therefore potentially cause suspended particulate levels to increase in areas immediately bordering the sites. The extent of increased ambient concentrations depends on factors such as the sur-

face area of the disposal site, the extent of dryness of the surface particles and the climatology of the area.

When one considers fugitive dust from coal ash disposal, it is well to keep in mind that dry soil can also cause analogous formation of fugitive dust. The difference between soil and deposited coal ash in terms of propensity to dusting is of course specific to the materials in a given locale.

The increased coal ash generation in Federal Region 6 of 58% in 1985 as a result of the National Energy Plan could cause significant site-specific particulate level increases near open disposal areas such as landfill sites. Mitigative measures such as the application of overburden, vegetative cover, and frequent watering would minimize these impacts greatly.

The Regional Ash Distribution Table indicates that in the year 2000, the National Energy Plan could cause particulate emissions from disposal operations to have the most significant increases in ash disposal in EPA Regions 6 and 3. This information by itself does not lead to the conclusion that impacts would be significant. The more important consideration at each site would be the site-specific requirements for application of available control technology.

Biological Impacts. Potential vegetation impact issues resulting from the disposal of coal ash could be of several types: vegetation loss by construction of disposal areas, effects on adjacent plant communities through disruption of local hydrology, and possible reduction in productivity due to fugitive dust. Potential positive impact issues could include enhanced surface mine reclamation and a possible increase in diversity of vegetation following reclamation of impoundments and landfills. Impact assessment has to be against the background of site-specific data and requirements for the possible application of available control and reclamation technology to minimize impacts for certain types of disposal.

Each disposal method has a different combination of potential impacts. Impoundments (lined and unlined) and landfills each require the disruption of an existing land surface and removal of any natural vegetation present. Creating impoundments or landfills may also modify the local water runoff patterns, thus affecting adjacent vegetative communities. For example, wetlands may become drier or upland areas may become wetter.

Coal ash disposal may not result in significant levels of fugitive dust, particularly with prudent design and operation of disposal methods. Impacts are likely to be minimal, but could include decreased vegetative productivity if significant dust deposits occur.

The use of surface mines as disposal sites may

Table 17. Physical properties of typical fly ashes.^a

Property	
Specific gravity	2.5
Approximate moisture content, (% H ₂ O)	25.0
Particle size distribution, %	
> 2 mm	0
0.074-2 mm	11
0.002-0.074 mm (silt size)	85

^aSource: (4).

potentially have positive impacts since such use may help rehabilitate the extreme topography of surface mine pits. Coal ash is generally alkaline and contains several chemical species including calcium, magnesium and potassium, which are essential plant nutrients. Thus, coal-ash-filled areas have a reasonable potential to be successfully revegetated and to become new habitats. In some localized situations, the type of vegetation selected for reclamation use could increase diversity. For example, edge habitats could be established in forested areas.

Impacts on terrestrial vegetation in the various EPA regions will be closely related to the amount of land needed for disposal of coal ash. As indicated in the section on land-related impacts, estimated areas needed by 1985 and 2000 are relatively small. While *some significant site-specific impacts are possible*, the overall impact in all regions appears small.

Since many of the utilities will be located near surface water sources, the types of vegetation disrupted will include a variety of plant communities. Specific studies for proposed ash disposal sites, which will most likely be required for disposal permits, can ensure that rare or endangered species will not be affected. Some sites will have only limited natural vegetation because of prior agricultural or industrial use.

All types of impacts are similar, with or without NEP. The NEP would have the effect of increasing the land area required for ash disposal by about 9% by 1985 and 12% by 2000. The increase in area of natural vegetation that is disturbed under NEP will be dependent on the specific disposal sites selected.

The major impacts of the disposal of coal ash on terrestrial wildlife will result from the loss of potential habitat and, in some cases, from enhancement of habitat associated with reclamation. The loss of vegetation could result in the local reduction of the carrying capacity for some forms of terrestrial wildlife. Recognizing that site-specific impacts are often overriding, the magnitude of the potential incremental impact on a regional basis is likely to be small since the incremental land area used for the disposal of ash in each EPA region under NEP is small.

Another potential impact exists from the chemical constituents of coal ash. A relatively large percentage of the composition of coal ash consists of relatively inert materials (e.g., silica, alumina, ferric oxide). These materials are relatively nontoxic to terrestrial wildlife. Moreover, the solubility of coal ash is relatively low. However, coal ash does have trace elements such as arsenic, cadmium, and selenium. Therefore, the contamination of surface and groundwater is a possibility. This contamination has the potential to cause chronic exposure of wildlife to low levels of trace elements of a poten-

tially toxic nature. It is unlikely that acute or chronic toxicity effects will be significant if the RCRA framework is successfully developed and implemented.

As in other areas of potential impact, the degree of site-specific implementation of available control technology is the overriding consideration in determining the incremental impact under NEP as it relates to aquatic biota. The available regulatory framework under RCRA, if successfully implemented, should prevent ash disposal practices with important adverse biological effects. With that in mind, the major potential concerns regarding aquatic biota are discussed below to help focus future regulatory efforts. All appear to be controllable with the application of siting and structural constraints which prevent the near-field entry of ash and/or ash liquor into surface waters.

The three characteristics of coal ash which appear *potentially problematic for aquatic biota* are: small particle size; relatively high percentages of ferric oxide in the solid fraction; and relatively high pH and trace metal concentrations in the liquor fraction.

Other characteristics about which too little data are available to evaluate the potential for problems are radioactivity and uncombusted carbon fractions of the waste.

The small particle size of coal ash (comparable to silts) implies greater potential for adverse impacts upon aquatic biota due to ingestion and impingement than for solids composed of larger particles. This would be of concern in any situation where higher aquatic organisms (e.g., finfish) are directly exposed to ash solids with relatively high trace metal levels which, if ingested, could be stripped and made available for subsequent accumulation or toxicity in the acidic environment of the digestive tract.

Ferric oxides, reportedly comprising up to 35% of ash solids, have poorly understood impact implications in aquatic systems. However, iron oxide flocs have been associated with reported fish kills, and the presence in surface waters of large quantities of ash rich in iron oxides could be considered problematical without more definitive data about opportunities for dissolution and flocculation as specific sites.

Ash liquors can exhibit pH values greater than 9 and a few trace metal levels in excess of recommended EPA criteria for the protection of aquatic life. In the absence of adequate mixing and dilution, these factors could create toxic conditions in affected aquatic systems. It is to be noted, however, that dilution of leachates is often likely. Cadmium, which is reported to be in excess of 10 $\mu\text{g/l.}$ in ash liquors, is a cumulative toxicant reported to adversely affect salmonid fishes and certain zooplankton in excess of concentrations between 0.4

and 1.2 $\mu\text{g/l}$, and less sensitive species between 4.0 and 12.0 $\mu\text{g/l}$.

On a regional basis, the potential for any adverse coal ash disposal impacts on aquatic biota appears to be greatest in EPA Regions 6, 8, 9, and 10. These areas show significant predicted volumetric and/or percentage increases over pre-NEP conditions for both 1985 and 2000. Regions 8 and 9 could be of special concern because of the importance of sensitive cold water fisheries in numerous small streams, in contrast to the strong preponderance of warm water ecosystems in Region 6.

Health Related Impacts. The major health concerns expected to receive regulatory attention in the disposal of coal ash as described in preceding sections may occur at several levels. They are all strongly dependent on a host of variables related to disposal technique, total quantity of ash disposed of and site-specific consideration, especially proximity to population centers. Broadly, health-related impacts could be divided into three kinds: occupational, local, and remote.

Occupational impact refers to effects on the health of workers involved in the disposal operations. These would differ according to location and type of disposal. In mine reclamation and landfill, fugitive dust is one of the significant distinguishing possibilities but is expected to be controlled. Industrial accidents and spills are considered outside the scope of this study.

Local impact refers to effects on persons in the vicinity of a disposal operation. This would be largely related to the effects of fugitive dusts and, perhaps more importantly, to potential impact on local ground and surface waters.

The remote effects comprise effects of materials, primarily trace metals, emanating from the disposal site as leachate, carried in surface and groundwater, and turning up in water supplies (streams or wells) used primarily for either human (or domestic animal) drinking water or irrigation.

The potential impacts in most areas will not come from the differences between the NEP and pre-NEP scenarios but with reference to the 1975 baseline, whichever scenario develops. The impacts would be principally site-specific. Figure 1 outlines percentage increases in various regions. Lacking further information, correspondingly higher levels of impacts could exist in these regions.

Whether the potential impacts are realized as actual impacts depends on a further set of variables including disposal methods, utilization of groundwater versus surface water for drinking purposes, the rate of groundwater passage through a fill site, the rate of leaching by surface water, the pre-existing composition of the leach water and its distribution

afterwards, the absorption of ions in the soil, the method of treatment of ash and the specific characteristics of a specific disposal site. In summary, these factors relate to possible regulatory actions enabled by RCRA.

These remarks pertain to disposal of both ash and sludge and, therefore, apply to the discussion of health impacts of sludge disposal.

Because of the large matrix of variables, each varying to some degree for each site, even within a region, it is considered unrealistic to attempt a refined quantitative analysis of health effects.

Furthermore, the regulatory framework, if implemented successfully, will by definition prevent adverse impact on any drinking water supply.

One can consider a potential worst case scenario in which a water supply is postulated to contain undiluted liquor and its composition is compared to recognized standards (for drinking water), and then examine what variables exist which might alleviate any concerns so derived. This scenario ignores many attenuating factors; actual levels of all incremental dissolved material in any surface or groundwater will be a fraction of those in ash liquors. Data developed in recent work and on the recent report of the NRC Committee on Drinking Water and Health (6) points to this.

The limited data available for ash liquors, which are subject to further variation depending largely on coal source, suggest that for most components there would not be major cause for concern. Possible exceptions are cadmium, selenium, and some other trace elements. This water would not in any case be considered a direct source of drinking water, and any outflow from an ash disposal site would need to be monitored and diluted or otherwise treated to increase its acceptability.

In addition to water-quality related issues, ash disposal more than sludge disposal will give some concern for fugitive dust emissions. This could therefore be mitigated by site-specific factors of construction design and operational procedures. The presence of radioactive elements in coal ash has been reported, but there are not sufficient data to determine whether there is cause for concern on this subject.

FGD Sludge-Related Impacts

Projected Production and Trends

Since the likelihood is that coal ash and FGD sludge will be disposed of together, either as fly ash admixed with FGD sludge (or SO_2 and ash simultaneously removed) or in the use of ash for the treatment of sludge, we have estimated production rates

Table 18. Regional sludge distributions—cumulative.^a

Federal Region	1975 10 ⁶ tons	1985				2000			
		Pre-NEP, 10 ⁶ tons	NEP, 10 ⁶ tons	Δ, 10 ⁶ tons	Δ/Pre-NEP, %	Pre-NEP, 10 ⁶ tons	NEP, 10 ⁶ tons	Δ, 10 ⁶ tons	Δ/Pre-NEP, %
1	< 0.1	4.94 (3.95)	6.13 (4.91)	1.19 (0.95)	24	21.50 (17.21)	22.68 (18.14)	1.18 (0.94)	5
2	0.2	14.82 (11.85)	18.65 (14.92)	3.83 (3.06)	26	63.98 (51.18)	67.70 (54.16)	3.72 (2.97)	6
3	1.2	18.20 (14.56)	26.45 (21.16)	8.25 (6.59)	45	60.58 (48.46)	113.76 (91.01)	53.18 (42.55)	88
4	1.7	38.74 (34.87)	46.23 (41.61)	7.49 (6.75)	19	156.53 (140.88)	199.81 (179.83)	43.28 (38.95)	28
5	3.1	51.62 (46.45)	57.72 (51.95)	6.11 (5.49)	12	187.90 (169.11)	229.07 (206.16)	41.17 (37.05)	22
6	<0.1	12.00 (9.60)	21.18 (16.94)	9.18 (7.35)	77	79.77 (63.81)	127.43 (101.95)	47.67 (38.14)	60
7	0.5	14.75 (8.86)	17.91 (10.75)	3.15 (1.89)	21	56.65 (33.99)	75.25 (45.15)	18.61 (11.17)	33
8	<0.1	1.29 (0.77)	2.15 (1.29)	0.86 (0.52)	67	3.83 (2.30)	9.59 (5.76)	5.76 (3.46)	150
9	<0.1	0.10 (0.05)	0.98 (0.59)	0.89 (0.54)	911	0.43 (0.26)	9.33 (5.59)	8.90 (5.34)	>1000
10	0.0	0.02 (0.01)	0.17 (0.11)	0.15 (0.09)	596	0.19 (0.12)	1.20 (0.72)	1.00 (0.60)	616
Total	6.8	156.48 (130.97)	197.57 (164.23)	41.10 (33.23)	26	631.36 (527.32)	855.82 (708.47)	224.47 (181.17)	36

^aNumbers of 1000's of acre-ft are in parentheses. Numbers may not add up to the last digit due to roundoff.

Table 19. Regional sludge plus ash distributions — cumulative.^a

Federal Region	1975, 10 ⁶ tons	1985				2000			
		Pre-NEP, 10 ⁶ tons	NEP, 10 ⁶ tons	Δ, 10 ⁶ tons	Δ/Pre-NEP, %	Pre-NEP, 10 ⁶ tons	NEP, 10 ⁶ tons	Δ, 10 ⁶ tons	Δ/Pre-NEP, %
1	< 0.4	13.13 (8.05)	15.77 (9.73)	2.64 (1.68)	20	49.78 (31.35)	55.54 (34.57)	5.76 (3.22)	12
2	1.8	42.13 (25.51)	50.16 (30.68)	8.03 (5.17)	19	162.26 (100.32)	186.40 (113.52)	24.15 (13.2)	15
3	9.6	126.54 (68.73)	143.83 (79.85)	17.29 (11.11)	14	378.03 (207.19)	485.50 (276.88)	107.47 (69.69)	28
4	15.3	194.84 (112.92)	205.78 (121.39)	10.94 (8.47)	6	624.10 (374.67)	679.05 (419.45)	54.95 (44.78)	9
5	22.5	284.16 (162.72)	295.65 (170.92)	11.49 (8.2)	4	848.19 (499.26)	915.56 (549.41)	67.37 (50.16)	8
6	< 0.7	48.32 (27.76)	78.52 (45.61)	30.2 (17.85)	63	333.56 (190.71)	449.98 (263.23)	116.42 (72.52)	35
7	2.5	51.68 (27.33)	55.48 (29.54)	3.8 (2.21)	7	185.49 (98.41)	209.14 (112.10)	23.66 (13.69)	13
8	< 1.8	25.77 (13.01)	30.97 (15.7)	5.2 (2.69)	20	72.43 (36.60)	103.76 (52.85)	31.33 (16.25)	43
9	< 0.4	10.81 (5.41)	17.67 (8.94)	6.86 (3.53)	64	84.66 (42.38)	117.0 (59.43)	32.34 (17.05)	38
10	0.3	0.83 (0.42)	1.82 (0.94)	0.99 (0.52)	119	3.81 (1.93)	10.14 (5.19)	6.33 (3.21)	166
Total	55.3	798.31 (451.86)	895.65 (513.30)	97.41 (61.42)	12	2,742.31 (1,582.82)	3,212.08 (1,886.63)	469.77 (303.8)	17

^aNumbers in parentheses are areas in 1000's of acre-ft. Numbers may not add up to the last digit due to roundoff.

for combined fly ash and sludge as well as FGD sludge alone. Tables 13 and 14 show the projections of the cumulative quantities and volumes of dry sludge and dry sludge plus ash, respectively, by region through the years 1985 and 2000 under pre-NEP and NEP conditions. Figure 2 shows the percentage increase in combined sludge and ash in each region due to implementation of NEP.

Tables 15 and 16 outline the breakdown of industrial and utility-related generation of coal ash and FGD sludges. Industrial wastes are likely to be a major part of national waste generation. Due to a lack of baseline data, impacts specific to industrial wastes are not considered separately. The impacts discussed broadly apply to both industrial and utility waste.

These estimates were prepared based upon the annual sludge rate projections in the Annual Environment Analysis Report (5) and assumptions regarding the distribution of coal consumption by type and region (see Tables 8-10 and 12). The basis for the projections is as follows. All scrubber systems are nonregenerable; Under the pre-NEP scenario, all coal-fired utilities are required to meet standards of 0.6 lb SO₂ emission/10⁶ BTU heat input for Western coal and 1.2 lb SO₂ emission/10⁶ BTU heat input for

all other coals. Under the NEP scenario, all new coal-fired utility boilers (and industrial boilers larger than 25 MWe) on line in 1984 and after, are required to meet BACT standards (81% removal of all sulfur from all coals burned). Sulfur and ash contents of coal given in Table 8 are after any assumed coal cleaning or processing.

In developing the cumulative figures for sludge and ash production, a linear relationship has been used between 1975 and 1985, and between 1985 and 2000 for each scenario.

It should be noted that the tonnages and volumes of sludges and sludge plus ash do not take into account the effects of any sludge treatment nor do the cumulative sludge plus ash volumes take into account variations due to simultaneous removal of ash and SO₂.

Treatment of FGD sludge or common disposal of FGD sludge and ash could utilize essentially all available coal ash in all regions except 6, 8, 9, and 10 (assuming 50/50 admixture).

The combined impact of wastes generated by industry and utilities is the focus of this paper. Baseline data are not available, as of this writing, to consider the impact of wastes from industrial boilers alone. It should be noted, however, that preliminary esti-

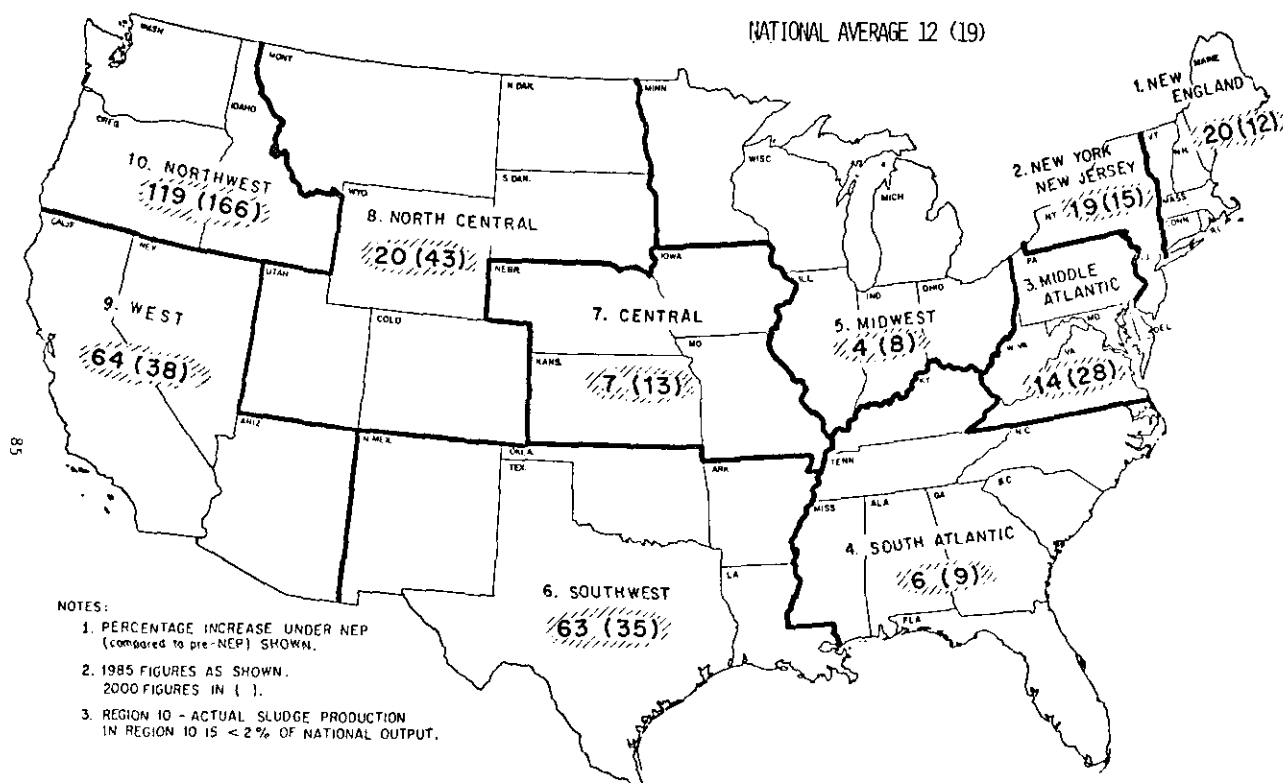


FIGURE 2. Regional FGD sludge + ash generation cumulative percentages in 1985 and 2000.

mates indicate that, by 2000, the generation of such wastes by industry, which is presently negligible, will be a sizable percentage of the total generation of ash and FGD wastes.

Environmental Impacts

The existing regulatory framework governing disposal of ash/sludge, if successfully developed and implemented, should prevent or minimize significant adverse environmental impacts. Hence, discussion of environmental impact of ash or sludge disposal is basically an attempt to focus on potential environmental issues.

Geologic and Soils Impacts. The most direct impact of disposal would be on the geology and soils of the area. The regulatory framework under which disposal of FGD sludges and fly ash would take place has been discussed above. Because of the minor volumes of land required for disposal, incremental impacts on land (under NEP versus pre-NEP) would be minimal on a regional basis. On a site-specific basis, the degree of potential adverse impact would be related to the extent of requirements for the application of available control technology. If fully applied, such technology is believed capable of preventing significant adverse impacts.

A broader consideration is the socioeconomic impacts of incremental land use discussed next.

Land Use Planning Impacts. A typical 1000 MW plant will require 400 to 700 acres for disposal of ash and FGD sludges over a lifetime of 30 years depending upon the type of coal to be used and the region in which it is located. The 400 to 700 acres include only the excavated area (landfill or impoundment); the actual disposal area required may be much larger since land would be required for access roads, truck parking, and unloading areas, and buffer zones to screen off the disposal area. It is anticipated that in the future public pressures will result in greater attention to buffer zones in populated or recreational areas to minimize the adverse aesthetic impacts of disposal areas.

The area required for disposal of such wastes from a typical industrial boiler of 100 MW is roughly 10% of that required for a corresponding industrial plant. Cumulative wastes generated by an industrial boiler during its lifetime will require from 40 to 65 acres for the disposal area along with perhaps an additional 50 acres required for unloading areas, vehicular movement and buffer zones.

In considering land-related impacts, two perspectives are useful: baseline land requirements for waste disposal under pre-NEP by 1985 and 2000; incremental land requirements under NEP over baseline land requirements by 1985 and 2000.

Table 20. Maximum total land requirements — cumulative.

Year	Baseline under pre-NEP, acres	Total under NEP, acres	Incremental change, %
1985	18,000	21,000	12
2000	63,000	75,000	19

Preliminary estimates on maximum land requirements for disposal area proper are summarized in Table 20. These estimates are the upper limit figures for disposal area proper if all sludge is disposed on land (i.e., with no utilization or other than land disposal method). Actual land taken for this use (including access roads, buffer zones, and other areas) would be higher. Actual land requirements depend on design of disposal systems.

These land requirements may result in land use controls by local communities. Land disposal areas are usually zoned for heavy industry. This land use may not be compatible with other uses such as residential, commercial, and recreational.

Conclusions on land impacts are noted. From a regional or state land use perspective, these land requirements are not large. Regions 5, 4, 6 and 3 (in that order) are projected to require maximum total land and maximum incremental land under NEP. While individual disposals would result in a loss of land for other purposes, the impact when considered on a regional or national scale is not very large. Much of the land area required for disposal between 1985 and 2000 would result from the establishment of new utility plants and industrial boilers. It is anticipated that these "energy centers" will require a larger land area than previous facilities and hence be sited in relatively rural areas. Political and economic factors are expected to increase land use planning for such uses and place additional regulatory constraints on utilities and industry. Potentially, demand could arise to combine utility plant and disposal area into one site, reducing requirements for off-site disposal.

Water Resource-Related Impacts. The overview of national water resources was presented above and applies equally to this section. The FGD sludge may be disposed of separately, or mixed with coal ash. Two disposal regimes are considered; inland disposal (on or beneath the ground), and disposal in the oceans.

Inland Water Resource Impacts. All disposal options previously cited have the potential for impacting the water resources of a region under the conditions of pre-NEP or NEP. However, successful implementation of existing environmental regulatory statutes could preempt each of the impacts discussed below.

The most likely form of impact would be the contamination of groundwater as a result of leaching of the sludge, either from percolation of rainwater through the sludge (in the case of landfill impoundments or surface mine disposal above the water table), or from the movement of groundwater through the disposal area (in the case of impoundment, underground mine disposal) or surface mine disposal below the water table. Wet impoundments have the potential for contributing directly to groundwater contamination as a result of seepage of the sludge liquor into the ground.

Chlorides and sulfates (primarily as calcium, sodium and magnesium salts) are the major soluble species in sludge and, in most cases, total dissolved solids (TDS) in the leachate plumes may exceed recommended drinking water standards. Soluble sulfite in leachate from sulfite-rich sludge may also be of consequence and represent an oxygen demand. However, TOS (total oxidizable sulfur) levels should be quite low in most cases. Other species present in trace levels (such as cadmium, mercury, and zinc) could also be substantially increased in waters receiving sludge leachate depending upon the relative low rates of the leachate and receiving water and their respective qualities.

Control techniques available for minimizing adverse impacts upon the water resource of an area include: sludge processing or treatment, choice of disposal method, collection and treatment of sludge leachate or runoffs, and site selection, based on hydrologic factors.

It is difficult to assess the potential impact on inland water quality as a result of the additional FGD sludge that would be generated under NEP, since several regulatory programs, including the Resource Conservation and Recovery Act of 1976, the Surface Mining Control and Reclamation Act of 1977, and the Safe Drinking Water Act, contain provisions that are intended to avoid or at least minimize the pollution of groundwater from leachates. If sludge disposal sites are designed properly and if the actual operations conform to the design expectations, one could optimistically conclude that incremental sludge disposal would have essentially no significant adverse impact on groundwater quality.

The principal concern, therefore, focuses on whether or not sufficient control measures exist for mitigating or avoiding any adverse impacts regardless of the implementation of NEP, and whether such measures can be effectively regulated to ensure compliance. In light of the existing data on sludge properties and on the effectiveness of the various control measures noted above, there appears to be adequate means for controlling the quantity of sludge leachate and, to some extent, its quality. Thus, the

impacts due to the incremental sludge or sludge plus ash caused by NEP will become a site-specific question as to whether a potential disposal operation is feasible and to what extent control measures are required. Since RCRA prevents deterioration of groundwater to the extent that its potential end-use is altered, NEP conditions would have minimal impact on groundwater quality if that law is fully implemented.

Furthermore, it is not expected that surface waters would be significantly affected because of the mandates of RCRA and the Federal Water Pollution Control Act. The principal determinant of impact would be in the choice of sites appropriate for disposal within the content of local availability. Disposal sites could most likely be located in mid or lower regions of a watershed having streamflow volume that would adequately dilute any seepage of contaminated groundwater.

Oceanographic/Water Impacts. Regulatory constraints to prevent adverse impacts due to ocean disposal are available under the Marine Protection Research and Sanctuary Act. Four principal areas of potential concern, relating to FGD sludge disposal, if practiced, in the ocean water environment, are: impacts of benthic sedimentation; impacts of sludge suspended in the water column; impacts of sulfite-rich sludge; and trace contaminant impacts.

The impact of the introduction of sulfite into the ocean environment as a consequence of FGD sludge disposal is of interest because: first, sulfite has a measureable toxicity; and second, it reacts with dissolved oxygen, leading to a depletion of dissolved oxygen.

If the FGD sludge solids would dissolve instantaneously upon being diluted and dumped, and if the oxidation in real seawater would proceed as rapidly as in uncatalyzed laboratory experiments, one would expect to find severe reductions in dissolved oxygen in the vicinity of the dump. However, calcium sulfite is very insoluble and it is unlikely that complete dissolution would occur in one or a few minutes. It is likely that solids dissolution rather than oxidation would be the limiting step in the dissolution/oxidation sequence.

The anticipated initial dilution of sludge liquor by a factor of 500 could result in concentrations of some trace metals (notably mercury, zinc, selenium, cadmium, and nickel) approaching or in excess of the "minimum risk" levels recommended by the National Academy of Sciences in 1972. This range of trace contaminant levels in the solid phase of FGD sludges encompasses considerably higher concentrations than found in the sample sludge liquors. As with the liquors, values in the high range have been obtained from sludges containing fly ash. As in the

case of sulfite, the impact potential of trace contaminants bound or adsorbed to the solid fraction of the sludge will be dependent upon critical variables such as dissolution rate and particle uptake by free-swimming organisms. Too little is known of these types of interactions over the short term to allow for a feasible prediction of quantitative impacts.

Applicable control options to reduce water-related impacts could be: the form of the sludge and its composition; disposal by dispersion; control of disposal method to concentrate sludge at the bottom; chemical treatment (e.g., adding lime and/or ash); and dumping in the deep ocean waters.

Anticipating the application of some of these control techniques, three options have been considered for ocean disposal: treated bricklike sludge in the shallow ocean; sulfate-rich sludge in the deep ocean; and treated sludge in the deep ocean.

Ocean disposal can be a significant disposal option in Regions 1 and 2. However, because of available control options and the projection that the increments in sludge and sludge plus ash, due to NEP, are small in these regions, and because ocean disposal would represent only a fraction of the sludge disposal, it is expected that there would be little impact on ocean water quality due to the implementation of NEP. Should any adverse affects be expected due to sludge disposal in the ocean, then the current regulatory disincentives to such disposal operations would preclude disposal under pre-NEP conditions. Then other means of disposing of the sludge or conversion to regnerable systems would be required.

Air Quality Impacts. Potentially important impacts, both subject to regulation under the Clean Air Act, are: fugitive dust emissions and, under some conditions, fugitive SO₂ emissions from the wastes.

SO₂ emissions could be significant if disposal is in surface or underground mines where run-off water could be acidic. However, sound control techniques would preclude release of fugitive SO₂ by such chemical destabilization methods. Except in underground mine disposal, SO₂ emissions are probably a minor factor.

The impact on air quality from FGD sludge/fly ash disposal is dependent principally on the moisture content of the material and disposal option. The high moisture content of the mixed FGD sludge/fly ash material would prevent emissions during transfer and transport to the disposal site; it is only the potential drying out of the surface particles at open pit operations which could cause fugitive emissions. Therefore, landfill and surface mine disposal operations could generate fugitive emissions due to wind erosion of the dry surface material.

Based on the regional sludge distribution table (Table 13), the major increases in sludge disposal in

1985 due to the National Energy Plan would be in EPA Regions 3 and 6. The major increases in the year 2000 are in the same two regions.

The level of increased ambient total suspended particulate (TSP) concentrations bordering a disposal site could be subject to the Prevention of Significant Deterioration (PSD) regulation in the Clean Air Act Amendment of 1977. The particulate concentration increases allowed under this regulation are 19 µg/m³ (annual geometric mean) and 37 µg/m³ (24 hour average, not to be exceeded more than once per year). Because the fugitive emissions from disposal operations are at ground level, the impacts near the source would be maximum and could, if controlled, exceed the PSD values. Applicants for FGD sludge disposal might be subject to PSD review. The expected ambient TSP concentration gradient from ground-level disposal sources is expected to be great, indicating that levels immediately bordering the sites could be high, but should drop off rapidly due partly to the settling rate of large particles (> 0.075 mm). The impacts on the ambient concentrations and the PSD increment would, therefore, be much lower at property line receptors if a buffer zone surrounded the disposal site. This zone may have a radius as great as 1 km for operations that have high fugitive emissions.

Terrestrial Biological Impacts. Potential impacts on vegetation from the disposal of FGD sludge are highly site-specific and similar to those resulting from disposal of coal ash. Since FGD sludges are often disposed of in combination with fly ash, impacts resulting from a combined disposal of sludge and ash are focused on. Again, site-specific application of control technology, which is available under existing regulatory mandates, would tend to minimize all potentially adverse impacts. Impact from landfills and impoundments is primarily disruption of resident vegetation on the site. Leachates may be a source of impact from landfills, surface mines and unlined impoundments used for disposal. Such leachates may have high concentrations of sodium chloride which exert osmotic stresses on plants. Plants exposed to leachates from FGD sludges and ash may or may not take up toxic amounts of heavy metals; such uptake depends on the total matrix in the soil.

Potential positive impacts from combined sludge and ash disposal include the return of surface-mined lands to a topography compatible with the surrounding area. The reclamation of surface mines, landfills and impoundments with vegetation somewhat different from the surrounding area would increase the diversity of habitats available.

Regional impacts on vegetation are a function of the additional land area required for landfill- and

impoundment-type disposal areas. The NEP initiatives would tend to increase the land required for disposal, assuming a mix of disposal options, but the overall regional impacts in any case are not large.

The major impact on terrestrial wildlife will occur from the conversion of potential habitat. In general, loss of vegetation has the potential to reduce the carrying capacity of some areas for wildlife. The magnitude of the NEP impact will bear some direct relationship to the collective magnitude of the disposal options involving land surface area and, more importantly, to the disposal sites chosen.

Another type of potential impact of FGD sludge on terrestrial wildlife relates to the possible impacts of some of the chemical constituents in groundwater. The leachate contamination of surface waters with potentially toxic trace materials (e.g., cadmium, lead, and selenium) is a possibility. Leachate contamination may occur both with surface and underground disposal options. This presents the possibility of chronic exposure of wildlife to potentially toxic trace materials. The ingestion of plant material grown within a leachate field could also create such exposure. The amounts involved are unlikely to produce acute effects. If unregulated, they could possibly have significant chronic effects, but there is not data available to evaluate this potential.

Viewed from the regional perspective, EPA Regions 4 and 5 would have a relatively higher potential to lose habitat because of the combination of options using land surface areas. With respect to leachate contamination, those areas using lined impoundments would tend to minimize the potential effects on ground and surface waters. Consequently, the potential impact on wildlife using such waters would be minimized.

Aquatic Biological Impacts. Considerations of the site-specific application of control technology and protective regulatory framework discussed in Section 2.2.4 also apply here.

In that context, characteristics of FGD sludge and sludge/ash combinations which appear potentially problematic for aquatic biota are: the combination of small particle size and physical instability in soil-like FGD materials; relatively high concentrations of certain dissolved species in sludge leachate; the reducing capacity of untreated, sulfite-rich sludges; and the presence of relatively high concentrations of several trace metals in sludge/ash mixtures and a few metals in sludges alone.

If enough soil-like FGD sludge or soil-like sludge/ash mixture reaches the bottom of a fresh or marine surface water body to form a sediment layer, the particle size and "mudflow" characteristics of the material could form a substrate unsuitable for colonization by a diverse benthic fauna. This appears to

have been the case in a shallow marine embayment where an inadvertent FGD discharge took place.

If freshwater systems should be exposed to leachate from the untreated FGD sludge, the relatively high concentrations of such dissolved solids as chlorides, sulfates, and fluorides could be problematic. Chlorides and sulfates would be of potential indirect concern as influences on salinity and the toxicity of other chemicals, while fluorides have the potential to cause health problems among populations of domestic animals (e.g., cattle) consuming fluoride-contaminated water.

There is evidence that sulfite-rich FGD sludges dissolve quickly enough to exert considerable oxygen demand. If such sludges reach surface waters with oxygen-limited environments (e.g., stratified lakes), the resident biota could suffer direct stresses due to anoxia and/or indirect stresses related to the tendency of a wide variety of contaminants to exhibit greater toxicity in oxygen-depleted environments.

Several trace metals (including mercury, cadmium, lead, nickel, iron, selenium, and zinc) have been reported in a limited number of samples of the solid and liquor fractions of FGD sludge/ash mixtures in concentrations in excess of water quality criteria recommended by the EPA for the protection of aquatic life. In some cases dilutions on the order of 10,000 to 1 would be required to achieve concentrations equivalent to minimal risk levels (e.g., for cadmium). The aquatic biological impact potential of the combined suite of trace contaminants in FGD sludge/ash mixtures is presently under study, but the area is still too poorly understood to project quantitative impact potentials or effects levels. Sludges alone appear to exhibit high concentrations of fewer metals than the sludge/ash mixtures, notably for such volatile species as mercury and selenium.

Control options involving chemical treatment of FGD sludges, especially those producing brick-like materials, seem to have the potential for reducing or eliminating the impact potentials discussed above and could play a major role in preventing adverse impacts under either a pre-NEP or NEP scenario.

On a regional basis EPA Regions 6 and 3 are predicted to experience the largest incremental sludge disposal requirements in the 1985 and 2000 scenarios. In the absence of site-specific considerations, correspondingly higher aquatic biological impact potentials could exist in these regions. Both have a variety of valued and potentially vulnerable coastal estuaries and warm-water systems, and Region 3 has a number of high-quality, cold-water fisheries in its northern portion. Regions 4 and 5 are both projected to experience large volumetric (small percentage) increments in sludge disposal. Both are largely characterized by warm-water systems gener-

ally having somewhat greater assimilative capacities than cold-water habitats.

Health Related Impacts

The classes of regulatory constraints and health concerns from disposal of FGD sludge and fly ash are the same as those outlined for ash in Section 2.3. It must be taken into account that a major portion of FGD sludges will be disposed of in admixture with ash, which tends to raise the content of many of the trace metals but, if properly treated, reduces their availability.

As with ash, the largest changes in impacts in most areas will not come from the differences between the NEP and pre-NEP scenarios but with reference to the 1975 baseline in comparison to either scenario. The impacts would be principally site-specific. Figure 2 outlines the percentage increases in various regions. Lacking further information, correspondingly higher levels of impacts could exist in these regions.

Whether increases in tonnage result in increases in health impact is again subject to all the variables cited in connection with ash disposal.

Here again, the "worst case" discussion is based on a comparison of undiluted FGD sludge and ash liquors with recognized standards for drinking water (6). From the median values for a limited number of FGD sludge analyses, data indicate that potential problem species may include beryllium, cadmium, lead (Eastern coal only), molybdenum (Eastern, but only one analysis), selenium, and sulfate. Individual high values additionally suggest perhaps local problems with arsenic, chromium, mercury, zinc, and fluoride. These concerns, of course, are based on considering each element or ion individually without knowledge of its chemical form in the liquor, and without allowing for synergistic adverse effects or antagonistic effects, both of which are known to exist among metals. Above all, this comparison ignores attenuating factors which would lead to actual levels for all these elements in any surface or groundwater much below those given for elutriated liquor. Further problems with straight liquor compositions arise from their high dissolved solids content (i.e., salinity) which could produce osmotic effects, in addition to specific ion effects.

Prevention of any of these concerns being manifested involves site-specific consideration of all factors previously enumerated. It would appear (with careful consideration of site location, surface and groundwater relations, prudent treatment and disposal methods, and other interrelated factors including regulatory mandates discussed in this paper) that the potential health impact of the disposal of

FGD sludges and ash could be brought within tolerable levels for protection of human health. Against this background, the incremental health impact on a regional basis of sludge and ash disposal due to increased coal utilization under the National Energy Plan would be well within manageable limits. Site-specific impacts in the absence of controls could be significant and require case by case evaluation.

Data Gaps and Research Needs

A number of programs have been undertaken (and are in progress) by the Environmental Protection Agency (EPA), the Department of Energy (DOE), the Electric Power Research Institute (EPRI), and others. These efforts have provided much of the baseline information for environmental assessment. Provided these programs continue, additional data and insight permitting better environmental assessment will be possible.

The EPA Program for Control of Waste and Water Pollution from Flue Gas Cleaning (FGC) Systems is designed to evaluate, develop, demonstrate and recommend environmentally acceptable, cost-effective techniques for disposal and utilization of FGC wastes, with emphasis on Flue Gas Desulfurization (FGD) sludge, and to evaluate and demonstrate systems for maximizing power plant water reuse/recycle. The program currently consists of 19 projects, each covering one of six areas of interest: (1) environmental assessment of FGC waste disposal/utilization processes and other power plant effluents, (2) assessment of the technology of these processes and development of new technology, (3) studies of the economics of these processes, (4) development of alternative FGC waste disposal methods, (5) development of new FGC waste utilization methods, and (6) development of methods for improving overall power plant water use. The environmental assessment efforts include FGC waste characterization studies; laboratory and pilot field studies of disposal techniques for chemically treated FGD sludges; characterization of coal pile drainage, coal ash, and other power plant effluents; and studies of attenuation of FGC waste leachate by soils.

Programs undertaken by others also focus on many of the above areas of interest.

Against this background of ongoing work, three major sectors exist where some additional information from new programs may be required.

Data gaps on disposal or utilization will not be fully covered by existing programs. Some potential questions are:

- Are there polycyclic aromatic hydrocarbons in coal ash or sludge?

- What are the radionuclides in ash or sludge, and do they appear in liquors or elutriates?
- What are the amounts of the several trace metals in ash and sludge, including antimony, molybdenum and boron? (More data are needed.)
- What are the biological and health effects of mixtures of trace metals (in the form found in liquors), such as zinc, copper, lead, mercury, cadmium or nickel in combination with selenium in particular, but also in other combinations? (Useful studies should be performed.)
- What is the uptake of potentially toxic materials by vegetation adjacent to disposal areas? (Further work is needed.)
- What are the levels of concentration of heavy metals and other potentially toxic materials in vegetation and surface water that may produce chronic health problems for wildlife?
- How does leachate move in-ground aquifers? (Further work is needed.)
- What are the socioeconomic impacts of disposal of ash and sludges (including criteria) on land use?

One key result of NEP would be to accelerate the production of wastes by industries. Generation of wastes is expected to grow rapidly between now and 2000. But the proportion generated by industry is anticipated to grow even faster and will be accelerated further by NEP initiatives. Conservation measures under NEP do not reduce quantity of total wastes.

Thus the generation of coal ash and FGD wastes will be somewhat shifted from large utility plants to a mix of utility plants and small (25 to 200 MWe) industrial units. The technological, environmental and socioeconomic impact of this shift is probably the key factor in FGD waste disposal. Programs focus-

ing on developing baseline data and information to regulate and guide this shift would be desirable.

Advanced combustion techniques like fluid bed combustion are anticipated to be in significant commercial use by 2000. Potentially lesser environmental impact will be one of the principal reasons to consider advanced combustion techniques. But then additional baseline data would be required on problems associated with such wastes. This would require completion of current programs in this field and probably some new programs.

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REFERENCES

1. Coal Fired Power Plant — Trace Element Study. Radian Report for EPA Region VIII under EPA Contract 68-01-2663, Volume I (TS-1a) and Volume II (TS-1b), Section I, September 1975.
2. An Evaluation of the Disposal of Flue Gas Desulfurization Wastes In Mines and the Ocean: Initial Assessment. Arthur D. Little, Inc., EPA-600/7-77-051. (NTIS No. PB 269-270/AS), May 1977.
3. Arthur D. Little, Inc., estimates.
4. Solid Waste Disposal Final Report. Radian Corporation, EPA-650/2-74-033 (NTIS No. PB 233-144), May 1974.
5. Annual Environmental Analysis Report. Prepared by Mitre Corporation, Consad Research, Control Data Corporation, and International Research and Technology; Report to ERDA, under Contract EE-01-77-0135, September 1977.
6. Summary Report: Drinking Water and Health. Safe Drinking Water Committee, Advisory Center on Toxicology, Assembly of Life Sciences, NRC, NAS, May 1977.